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3441

1. ultra violet photography
2. radiography.
3. atomic particles
4. Motion analysis
5. infra red sensitivity

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12 MS

MODERN APPLIED
PHOTOGRAPHY

↑
LOOKING
NORTH

↑
DIRECTION OF FLIGHT

LOOKING
SOUTH
↓



Courtesy: Royal Canadian Air Force

FRONTISPIECE

A tri-camera survey photograph, horizon to horizon. From a series of such records, the first photographic topographical map of Canada was produced in 1945. The photographs were made from 20,000 feet. These maps were the first of their kind to be made by such a technique, and this particular record shows Camsell Bend in the District of Mackenzie, N.W. Territories.

TECHNICAL TRENDS SERIES

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MODERN APPLIED PHOTOGRAPHY

By G. A. Jones,
M.A., A.R.I.C., F.R.P.S.



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PREFACE

PHOTOGRAPHY is so widely used in modern times that it would be quite impossible to condense all aspects of it into a book of average length. The brief summary possible in this volume is therefore intended merely as an outline of its major applications, and is directed towards those not mainly concerned with the art or science of the subject. Many important applications have necessarily been omitted but the Bibliography at the end of the book includes suggestions for further reading.

There is a danger when covering such a wide field that no single part of it will contain enough general detail to sustain the reader's interest. It is for this reason that many otherwise interesting applications have been excluded to make adequate space for those selected.

As far as possible, technical terms have been omitted, though it has been assumed that the reader possesses a general knowledge of elementary photographic principles. Today the widespread popularity of amateur photography ensures that few people interested in scientific or technical subjects are without some knowledge of the process of making photographs.

The number of applications of photography is continually growing and new photographic techniques are constantly appearing to expand the field. Where possible, an attempt has been made to show likely future trends, while those sufficiently interested can follow current developments through the photographic press. The

PREFACE

publications of the Royal Photographic Society provide one of the few sources of full and up-to-date information on applied photography.

My grateful thanks are due to Kodak Ltd. for permission to reproduce certain of the illustrations appearing in this book, assistance in collecting many of the prints, and part of the information used in the text. Also to Dr. D. A. Spencer for bringing to my attention a number of the most interesting applications described, and Miss M. D. Gauntlett of the Kodak Research Library for her aid with the literature of the subject. Finally, to Mr. R. McV. Weston who read the manuscript and made a number of constructive suggestions for its improvement.

INTRODUCTION

FOR OVER one hundred years photography has shown a record of constant technical progress. Materials, equipment and technique have all made remarkable advances—from the early silhouettes and posed portraits, taken by means of exposures extending over hours in bright sunlight, to the modern snapshot, which can be taken by anyone under almost any conditions. Photography is undoubtedly known, if not practised and understood, in every civilized household; the snapshot album, the portrait on the piano, the book illustration, the cinema film, have brought it into our daily life. And yet very few, even among scientists and technicians, realize that far more photographic material is employed for technical work of one type or another than for artistic purposes or amusement. In point of fact, the amount of photographic material now used for technical purposes alone is twice as much as the total used for all purposes prior to 1939. Moreover, photography has played a major part in the amazing scientific progress of the last century, and there are signs that its influence will be even more important as its special attributes become more widely understood and ways are devised of applying them to the solution of technical problems.

Photography has many aspects and applications which will unfold as this book is read. These may be considered from two points of view: that of the photographer, or that of the man who requires the production of a photograph.

The field is so widespread and so complex that both points of view must be examined if some sort of order is to be achieved. This chapter, therefore, explains the fundamental principles of photography: the application of these principles will be dealt with in subsequent chapters.

Our first concern is with the action of radiation in the form of light or certain of the invisible rays, on the sensitive photographic material, be it plate, film, paper or some special sheeting. The eye sees by means of light alone, but light fills only a minute band of the electro-magnetic spectrum. Moreover, the eye loses the image the moment after it has perceived it and can be useless as a method of observation under many conditions of brightness, speed or atmosphere. Photography provides us with a super-human eye—one which can “see” over a wider range of conditions, with greater accuracy and in a shorter time than any human eye, while at the same time retaining a lasting record in place of a mere glimpse. Considered solely as a means of recording, and compared with any other known technique for the reproduction of images, photography is rapid, accurate and clear.

The photographic process may conveniently be divided into the main operation, the exposure, which normally produces no visible image, and the “processing”, which may follow the exposure immediately or after some considerable time. The usual result of these operations is the production of a “negative”, i.e. a record in which the blackening which constitutes the image is in direct relation to the brightness of the light falling on the corresponding parts of the photographic material. A “positive” can, however, be produced from a negative by the simple repetition of the process, using the negative as a starting point; in other words, the negative is “printed” on to a sheet of suitable light-sensitive paper or film. Thus,

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returning to the fundamental principles, the exposure and the processing (i.e. development and fixation, or reversal) are the two most important features of the operation.

Exposure may be of very short duration. Each particular type of material needs a certain minimum of light action in order to avoid "under-exposure", but this may be achieved in a very short period provided the light intensity is high enough. Hence the record may be made in a very short time. Before it can be examined, however, the time taken by processing must elapse, and here the length of time depends upon prevailing conditions. Under normal commercial conditions, hours may be required to produce the print or record, whereas under the most favourable conditions it can be produced within a few seconds.

The material on which the record is made consists of a light-sensitive layer held on a "base" material. The light-sensitive layer may be of several different types but normally consists of tiny crystals of silver salts held in a suitable material such as gelatine. These crystals are so minute that even at their largest they can only be seen under fairly high powers of magnification. Nevertheless they produce a pattern which gives an appearance of granularity at much lower magnifications, and this considerably reduces the capacity of the material for recording detail. This granularity or "graininess" is highest with the more sensitive or "fastest" materials and is usually not objectionable with slower materials. Such fast materials will, even so, clearly resolve about 700 lines to the inch, while the very slow plates designed for recording tiny images will resolve over 25,000 lines to the inch.

In this connection it is worth remembering that the material used is normally called upon to record the image

cast by a lens. In such cases the characteristics of the final record are usually determined at least as much by the lens as by the photographic material. The lens not only affects the contrast of the image and the degree of detail recorded in it, but also the duration of the exposure and the relative dimensions of the image. However, as we are here more concerned with the capabilities of the photographic material, confusion will be avoided by ignoring subsidiary effects introduced by the exposure equipment used.

It has already been mentioned that the mixture of light-sensitive crystals and gelatine (technically called the "emulsion", though it is in fact a suspension) can be coated upon various types of support. Glass and paper were used until clear celluloid of uniform quality became available, and all three have since been used extensively. More recently, film has been coated upon a variety of cellulose esters, though some other plastic materials have not proved very satisfactory. For specialized technical work, the emulsion can now be used on practically any solid material, though care has to be exercised in the case of some which show a chemical reaction. The methods used for such work are described in a later chapter. Unfortunately, the emulsion is very easily attacked by a variety of elements and their compounds and it is also susceptible to damage by water and other liquids, by heat, and by mechanical abrasion. Such troubles can sometimes be overcome by suitable protective lacquer layers, by specially compounded emulsions or by carefully chosen methods of handling.

Another physical drawback is the dimensionally unstable character of any layer consisting largely of gelatine. Processing has to be carried out in solutions, which cause the gelatine to swell considerably, and when dry again

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there is little likelihood of any two portions of the image returning to the relative positions which they occupied at the time of exposure. Even changes in atmospheric humidity can produce appreciable changes in dimensions, though these can be minimized by the selection of a suitable base material on which to coat the emulsion. Metal is sometimes chosen; the high coefficient of expansion of most metals makes them rather sensitive to temperature changes, but temperature can usually be controlled, within the necessary limits, rather more easily than humidity. Glass comes into its own in this type of application. For years the photographer who uses glass plates has been derided and considered out of date. They are heavy, bulky, dangerous and fragile; they have at least two serious practical photographic drawbacks. But, on the other hand, they provide for the emulsion a flat, protective support which does not alter appreciably in dimensions under violent changes of humidity and temperature. Moreover, years of research have evolved methods of manufacture which ensure a firm key between the emulsion and the glass, reducing any "creep" between them to proportions negligible for most types of work. At its best, the emulsion will adhere so firmly that pieces of glass are torn from the surface of the plate when the layer is stripped off. Unfortunately, at its worst—and some emulsions are more prone to this failing than others—the layer will slip off the glass as soon as it is wet and float in a little roll which makes no pretence of dimensional stability. But such is the ingenuity of man, that even this feature has been turned to some value in certain fields (see page 110).

So far, little has been said of the light-sensitive properties of the emulsion. The crystals in it are primarily sensitive to blue and violet light and to a long range of invisible

short-wave radiations stretching down below the violet end of the spectrum, through the near ultra-violet to the far ultra-violet and on to X-rays and gamma rays. Absorption by the gelatine reduces their sensitivity in the mid ultra-violet and little is known of the region where the far ultra-violet merges into soft X-rays, but otherwise a single common "blue sensitive" plate will provide, in one step, this prodigious addition to the power of the human eye.

The emulsion is not intrinsically sensitive to colours other than blue and violet, but the addition of suitable dyes can easily make it so—and, moreover, enhance its over-all sensitivity to light. In this way, sensitivity has been increased, through the longer wave-length green, yellow and red portions of the spectrum and beyond, out into the invisible infra-red. Such sensitivity does not extend as far as the "heat-rays", though it is possible to take photographs by means of much longer wave-length infra-red rays by an indirect method which is described in Chapter 6.

The sensitizing of the emulsion to all wave-lengths of the visible spectrum also makes possible photographic records in natural colour. Clerk Maxwell originally demonstrated that only three colour records were needed to produce a full colour reproduction, although he had only non-colour-sensitized plates available and had to utilize their minute sensitivity to green and red light to prove his theory. Modern colour processes are all based upon an analysis of the colours of the subject into their constituent three primary colours, which are recorded and used to synthesize the colours of the subject. Such a technique would be quite impracticable if emulsions sensitive to blue, green and red light were not available.

It is worth remembering that the sensitivity of the

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emulsion to such a vast range of wave-lengths of radiation does more than merely extend our effective vision—it makes possible entirely new methods of investigation. The use of X-rays for examining thick metal parts would have been greatly handicapped if it had had to be carried out by means of a fluorescent screen alone. Investigations by ultra-violet and infra-red would have been very tedious, if not impossible, without the photographic material to convert the invisible images into black and white.

Another important property of the photographic emulsion is its ability to record intensities of light outside the range covered by the eye. This property has enabled astronomers not only to record many millions of stars which are invisible to the eye even under the largest telescopes, but also to analyse their structure and determine their speed and the direction in which they are travelling. At the other end of the brightness range, the interior of white-hot furnaces and the detail of the burning of explosive materials, which completely dazzle the eye, can be recorded for subsequent study.

Photography under such conditions naturally depends upon the exposure time which can be given. The astronomers have been able to compensate for the movement of the Earth during the long exposure time required, by devising ingenious mechanical devices for moving the telescope proportionally, the image remaining on the same part of the plate for hours. The very short exposures needed for the recording of bright objects can be achieved by suitably designed shutters, though it is by no means a simple matter to devise a mechanical shutter which will give a single exposure of very short duration, without lag, bounce or lack of reliability.

In cases where very short exposure times are attainable

there is the added advantage of arresting movement. The ability to "freeze" high-speed movement by means of extremely short exposure times is one of photography's greatest assets. The eye is incapable of recording any impression which may be gained during a brief glimpse of an object and does not furnish the memory with sufficient data to be of much assistance. Photographs, on the other hand, taken at exposures as brief as a millionth of a second or less, can be very clear and of great help in analysis. Such records are not restricted to highly luminous objects, as it is possible to provide flashes of light of extremely high intensity to illuminate almost any subject. These, incidentally, make an elaborate high-speed shutter unnecessary, the duration of the flash itself being sufficiently short to arrest movement.

Photography, however, goes much farther than the mere stopping of movement. By means of cinematography, movement can be recorded. Admittedly, the illusion of movement gained by watching a progressive series of still pictures on a cinema screen is by no means the same to the scientist as the examination of the actual movement itself—the regrettable tendency of the spokes of bicycle wheels to move in a direction contrary to mechanical laws is a clear example of that. Nevertheless, the film has a large variety of uses. Not the least of these to the technician is its ability to speed up or slow down movement. The reader will probably be familiar with the fascinating "Secrets of Nature" and other instructional films showing the movements of plants speeded up very considerably. Similar films have been made of cloud movements and other slow phenomena. Slow-motion films have been used to an even greater extent. Films employing a degree of slow motion have become familiar in news-reels of sporting events; they have been used for analysing the performance

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of athletes and instructing others in similar actions. The camera has developed far beyond this, however, and movements of machines, bullets in flight and explosions can be slowed down five hundred times or more by means of cameras running at very high speeds. Films are not usually exposed at over about 10,000 pictures per second, but specialized recording cameras have been evolved which can take a relatively small number of pictures at speeds approaching 100 million per second.

We have now moved away from the properties of the emulsion as a factor in the wide range of photographic applications and are dealing rather with the instruments which make use of photography as a recording medium—cameras of one form or another. Of these, the cinematograph is by far the most important, but there are others which should not be neglected. An inseparable ally of the cinema camera is the sound-recording camera which enables photography to record sound as easily as it records pictures. Another is the stereo camera which, although now somewhat out of favour, has progressed far beyond the Victorian peepshow and could well be used more than it is, both for amusement and technical purposes. For the stereo camera does more than merely record what the eye can see; it actually extends human vision by enabling “depth” to be accentuated—a factor of vital importance in, for example, aerial photography. Other specialized cameras are to be found in almost all fields of science and technology. Many are mentioned in other chapters, though it would be impossible to classify here all that have been made, let alone describe the individual instruments. In “ordinary” photography—used for snapshots, portraits, press photographs and pictorial work—the range of cameras is relatively small and very few instruments are individually made. In scientific work,

however, the camera usually has to be made or adapted for the job, hence the variety of those which have been used at one time or another is very large.

In such cases the camera itself is often unimportant. It is, after all, merely a light-proof box used to hold the lens, with its ancillary equipment, in the right position relative to the photographic material. It is often greatly elaborated and may not easily be recognized in its original rôle, but its fundamental purpose remains unchanged. An important fact, obvious but often overlooked, is that the camera can fairly easily be used to record through a wide variety of instruments. The ease with which the field of view in, say, a microscope can be quickly and accurately recorded is itself of prime importance, but to this is added the full range of perception beyond that achieved by the eye. Thus photography greatly facilitates the use of scientific tools such as the infra-red microscope, the ultra-violet microscope and the X-ray diffraction camera; in fact, it might well be maintained that without photography many of them would be too difficult to use for anything more than very rare research work.

Thus we see the framework of the story of technical photography; the skeleton round which following chapters will make the flesh. Behind this story lie many years of intensive research upon emulsions, sensitizers, base materials, lenses and equipment of all types—and many years of struggle to use photography under ever more severe conditions. Many materials and techniques have been evolved which are useless in any branch of investigation except the one for which they were designed. The constant demand from, and endeavour by, engineers, doctors, astronomers, printers, detectives, surveyors and research workers in practically all branches of science, have led continually to new applications and to better



ATE I

Courtesy: Kodak Ltd.

The Recordak Junior, which is used both for recording documents and reading them. It incorporates a camera and a projector in the housing at the top, the original documents and the projected image being positioned on the white sheet at the bottom.

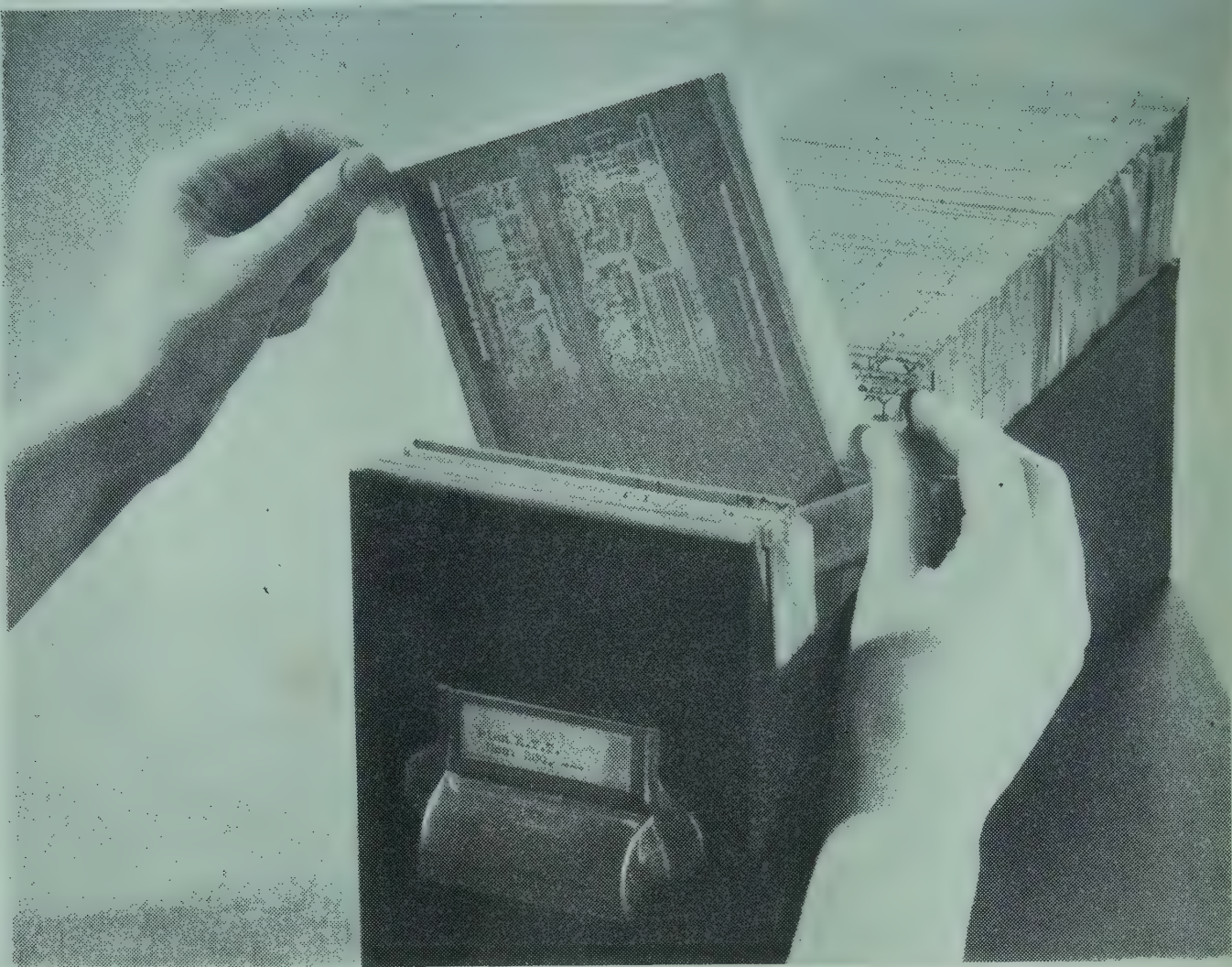


PLATE II (a) and (b)

Courtesy: Photostat Ltd.

(Above) This drawer of Statfile negatives contains all the drawings shown in (b) (below). From such negatives it is possible to make enlargements containing all the detail shown in the originals.



INTRODUCTION

equipment for the employment of proven methods. Certainly, the story has not always been one of continued success: for example, intensive work on the detection of objects in mist and fog by means of infra-red photography was rendered obsolete by the invention of radar, which is overwhelmingly superior for the purpose. By and large, however, photography is being used for discovering more about our surroundings, from the distant stars to the most minute structure of the atom, as well as helping to achieve greater efficiency in the production of the more mundane things around us.

Chapter 2

PHOTOGRAPHY AS AN AID TO MEMORY

A PHOTOGRAPH is a faithful record. It can be used by a multitude of people and can register unaided far more than the human eye can perceive. This attribute may be applied in various ways.

Most photographic applications involve the production of a record of one form or another, but let us first consider photography used solely as a means of recording, as in document copying, plan copying and similar bibliographic applications.

There are three main advantages in the use of photography for document copying. The photographic copy, which is sufficiently near facsimile, eliminates those errors which so readily occur in even the most careful manual copying, typing or tracing. Provided the reproduction is clear, the accuracy of the matter in the copy can be relied upon without checking. This saves time, in addition to that which would have been expended in making the copy. It also ensures that the original layout and appearance are retained, often difficult with other methods of copying. Copies can also be made to any suitable size, so making possible the use of reduced photographic copies as a method of storage of information. Given favourable conditions, it is possible, by means of micro-copies which are large enough to read under a magnifying glass, to save 95 per cent. of storage space. This is by no means the limit of reduction and much less space can be occupied by micro-copies if desired, though very small images are

difficult to read without elaborate magnifying equipment. Finally, there is the advantage of being able to make any number of identical copies, each of which may (under certain conditions) actually be of better quality than the original.

It is often, though not always, possible to produce copies at various magnifications to suit different needs, to select portions of an original by colour (e.g. to reproduce only the red and black lines on a plan, omitting blue and green ones), or to make reproductions on a variety of types of base material. Whatever the base, the records are less inflammable than most ordinary types of paper, usually consisting either of paper in some form (the emulsion coating reducing their inflammability) or of a cellulose ester of low inflammability. Both this and the ease with which several duplicate records can be made is important as an insurance against loss.

Existing methods of copying vary considerably. Generally, copies made to approximately the same scale as the original are reproduced on some form of opaque or translucent paper, while reduced copies are photographed on transparent film. New techniques are, however, now being evolved which may introduce important changes in present copying methods. To understand them properly, let us consider the accepted techniques at present in use.

The simplest technique is to print through the document while it is held in contact with a piece of sensitized paper. This is well known to most technical people in the form of blue-printing or one of the similar modern systems. Blue-print paper is one of the oldest photographic materials, although not one which uses silver salts. The light-sensitive coating is a pale yellow mixture of ferric salts and a soluble ferricyanide. On exposure to light behind a document, the ferric salt is reduced to the ferrous state and reacts with the ferricyanide to produce insoluble

prussian blue. Blue-print paper can be developed and fixed, in one operation, by washing it in water. A more modern method of processing it is by damping the surface with a solution which converts the remaining ferricyanide to a colourless salt which does not react with ferrous salts. The paper needs only to be damped and will thus dry almost at once. Blue-prints produce what is really a negative image; in other words, an original consisting of black lines on a white base is reproduced as white lines on a blue background. This disadvantage can be overcome by use of the diazo processes.

The various processes employing diazo compounds depend upon the special character of the latter, which are decomposed by light to give substances which will not produce azo dyes, as they themselves do when allowed to react with amines or phenols. Thus a sheet of paper sensitized with diazo compounds responds to exposure in such a way that a positive is produced. Where light falls upon it, the ability to form a dye is destroyed, but behind the lines of the document the diazo compound remains and can then be made to combine with an amine or phenol compound to give a coloured image, usually dark blue or brown. This "coupling" compound can either be applied as a solution used to dampen the surface of the paper or it can be incorporated with the diazo compound in the paper under acid conditions which prevent them "coupling". In the latter case, the paper is developed by damping with an alkali or by exposure to ammonia vapour.

Another process which is interesting, though rather less widely used, is that known as the "True-to-Scale", an attribute which it actually possesses only in a superficial sense. In this, an exposed blue-print is squeegeed to the surface of a layer of jelly containing a ferrous salt.

When this reacts with the ferricyanide remaining in the portions of the paper protected from light action, the jelly surface is tanned image-wise and becomes receptive to greasy ink. The surface can then be inked while wet so that the ink is retained only by these portions, and afterwards can be printed mechanically on to sheets of paper. Up to 200 identical copies are obtainable from each pad before the jelly surface wears out. The prints so produced, being in ink and on paper of any desired quality, are usually more crisp, clean and attractive than either blue- or diazo-prints, though much depends upon the original document.

All these processes rely upon the use of an original document which is of a translucent material on one side only, and of fairly high, consistent quality as regards density and width of line. Generally speaking, photographs, paintings or other tone illustrations cannot be reproduced by these processes except in the most crude manner. Moreover, reproduction can only be at approximately the same size as the original. In spite of their disadvantages, the processes are, however, widely used because of their comparatively low costs and simplicity of working. They find a ready application in drawing offices, where plans, machine drawings and diagrams have to be reproduced in quantity, both cheaply and quickly.

Ordinary photographic paper (i.e. paper coated with silver salts in gelatine) can be used in precisely the same way as blue-print or diazo paper and will usually give a black image of superior quality to either and in a fraction of the exposure time. Disadvantages are its higher initial cost, mainly due to greater complexity of manufacture, and a much longer processing time, involving a greater number of stages. Special "document papers", suitable for such work though not for ordinary printing

or enlarging of pictures, are marketed at lower prices. There is no doubt that the disadvantages of normal processing could be minimized by special methods and equipment if considered worth while. This would, however, defeat the object of the use of silver-salt emulsion, which is better adapted to deal with certain other aspects of document copying, in which it holds undisputed sway.

One technique is available which enables copies to be made, without a camera, of documents on opaque materials or which occupy both sides of the paper. This is difficult or impossible with all document-copying processes except those using silver-salt emulsions. The technique, called reflex copying, enables the copying of diagrams or script from books, typed reports and handwritten manuscripts to be undertaken. It has the advantage of being able to reproduce fainter lines and to more accurate dimensions than any of the other processes already described. The material, which can be a plate, film or paper, is placed face down on the matter to be copied and is exposed through the back. Although this "fogs" the whole emulsion layer, an image of the document is impressed upon it because of the differing reflectivity of the various parts of the page. Where there is a black line, the light passing through the emulsion layer will be absorbed, whereas light striking the white background of the page will be reflected backwards and forwards between the page and the emulsion layer, thus producing an appreciably heavier exposure in this area. The final result is a negative with dark grey tones or "fog" where the lettering or lines lie on the document, with a background of a more opaque tone. At first sight the image appears dirty, degraded and useless, especially as it is reversed laterally when viewed face up. From it, however, on a suitable printing paper, a first-class repro-

duction of the document can be obtained. The only requirement (if a properly designed reflex printing paper is employed) is a clean background to the document, to enable enough light to be reflected from it by comparison with that reflected from the black lines.

Although the processes just considered are widely used, it is the camera which really introduces versatility into document copying, for only by the suitable use of a lens can substantial alteration in scale be achieved. The camera also enables the image to be reversed from left to right, if desired, so that the negative itself can be read normally and a positive dispensed with. For example, a "Photostat" camera photographs documents on to a roll of paper. Normally, such a paper negative would be impossible to read, except through the back when held up to the light, because it would be laterally reversed. However, by placing a reflecting prism over the lens this reversal is eliminated and an added advantage obtained of being able to place the document or book flat, face up upon a table below the lens in front of the camera. Incidentally, a negative copy causes less eye-strain owing to the reduction of glare from the black background.

Theoretically, the copy can be made to any desired magnification. In practice the limits are dictated by the smallest size which is easily readable (usually not much less than $\frac{1}{4}$ size in the case of reading matter or $1/10$ th size with bold diagrams and drawings) and the largest size of paper available. The paper is made in a width of 18 inches, and 18×24 inches can thus be regarded as a convenient maximum. As the roll is 350 feet long, a large number of copies can be exposed quickly one after another. Such copies are relatively cheap, since no unused intermediate print is necessary. If positive copies are required, the negative is placed on the copyboard when dry and re-

photographed. Any number of copies of a document can be made by repeated exposures of either the original document or the negative.

Usually, each portion of paper is torn off as it is exposed and processed in dishes behind the camera (in subdued lighting) or in a separate dark-room. For large installations the front of the camera is in one room, containing the copyboard and bright lights, while the back is in an adjoining dark-room. Equipment has been marketed which enables the exposed paper to be developed in the camera and withdrawn from the back for the final operation of fixing and washing. So far such methods have been somewhat clumsy and have involved processing times which restrict the full use of the exposing end of the camera. Recent developments suggest that such restrictions need not apply, and that wet, processed prints (if not dry ones) can be withdrawn from the back of the camera as fast as they can be exposed.

Photostat copying, by comparison with copy-typing, hand copying or ordinary photography, constitutes a quick, easy and not over-expensive method of copying reading matter. If delays occur or expenses soar in practice, it is due to the method of organizing the service and not to the technique itself. For copying large illustrations, such as plans and drawings, blue- and diazo-printing are cheaper and quicker, even though they may provide somewhat less clear results. Photostat copying is, however, superior because it facilitates reduction in scale, and enables storage space to be considerably reduced.

As stated above, Photostat copies are not usually made to a high degree of reduction. Paper prints are not easy to read if they are very small, and there is at present no easy way of enlarging them clearly without elaborate magnifying apparatus. The answer to this problem lies

in the use of film. Because of its transparency, records on film can be put in some simple form of lantern or enlarger which will project an enlarged image for visual examination or for recording on sensitized paper.

A simple attachment to a Photostat camera enables records to be made on fairly small pieces of film, which can be stored until required and then enlarged to the original size by projection through the camera. Such records save considerable space in drawing offices and yet are large enough for examination in the hand when brief identification or casual reference only is required. One firm possessing over 500,000 drawings occupying 1,500 square feet of floor space was able to accommodate them all in one filing cabinet. Photostat copies on film can readily be sent by post or air mail and can often be used without making expensive full-size copies of the original drawings. Ships or aircraft can carry their own constructional drawings, for reference if repairs are needed. In the Statfile recorder, films $6\frac{1}{2}$ inches $\times$ $4\frac{3}{4}$ inches are used. Even when protected in envelopes, fifty of these occupy only about an inch of drawer space and each will record the finest detail contained in 40 inches $\times$ 30 inches or even larger drawings. Such films are easily kept in a file and can be given a cursory examination with the naked eye. More critical examination is possible in a special viewer or by replacing the record in a camera, attaching a lamp-house behind the latter and making a print from the image projected upon the copyboard. Special papers are available which have the emulsion coated upon a translucent base. Prints made on these are suitable for use as masters in blue-print or diazo printing machines.

For purposes where an even greater saving in space is desired, particularly with documents smaller than those

normally encountered in drawing offices, much greater degrees of reduction in size are possible. Such "micro-photographs" are usually made on 35 mm. or 16 mm. film in sizes between 36 mm. $\times$ 24 mm. and 10 mm. $\times$ 7 mm. They represent the maximum degree of photographic reduction in commercial document copying at present practicable; the film record occupies only about one per cent. of the area of the original document recorded. Moreover, the use of lengths of film permits the very rapid reproduction of single documents. Cheques or other small papers can be fed into a Recordak machine and photographed at a speed of up to 5,000 an hour. The machine records each document as it passes over a roller and an ingenious mechanism ensures that the film is only moved and exposed while a document is passing through, although the roller rotates continuously. Thus no film is wasted in the pause between feeding in one document and the next, all the records being made close together, however long the time interval between them. With some models both sides of the document can be recorded simultaneously. This system is often used merely to record, as a safeguard against loss or fraud, such documents as the cheques passing through a bank's clearing house, or the incoming entries, complete with serial number and date, in football pool offices

Other microfilming camera equipment, working at a slower speed, is designed for copying pages of books or larger sheets than the Recordak machine will handle. These cameras can be used at varying degrees of reduction, to allow widely differing sizes of document to be copied. They usually employ an automatic system for switching on lights, exposing and moving the film to the next frame. The spools used contain 100 feet of film, allowing 4,000 documents to be copied per spool on 16 mm. film and

between 800 and 1,600 on a 35 mm. spool, depending upon the frame size used.

Film records of this kind are conveniently examined by means of a "reader" consisting essentially of a projector, housed in a compact box, which throws an enlarged image upon a screen. It is, therefore, so easy to read the records in this way, by winding the film on frame by frame, that paper enlargements are unnecessary except to provide extracts to send elsewhere or of matter used for reference purposes. Enlarged prints, when required, are of reasonable quality, though the sharpness of the detail depends upon the frame size and the degree of reduction used. Naturally, such small frames will only satisfactorily record documents of normal size which do not contain extremely fine detail. A double-page spread of *The Times* newspaper is about the maximum which can be adequately recorded on 35 mm. film, even the smallest type being legible in a special viewer or on paper, when enlarged back to its original size. This could not, however, be done on 16 mm. film, which would only reproduce such detail adequately if the page were photographed in ten sections of equal area.

Owing to the small size of the records and the very small amount of labour involved in making them, this form of recording is cheap, but it is not well adapted to copying *small* numbers of documents. Indexing and selection of individual frames is not so easy as turning the pages of a book (although selecting a 100-foot roll of film is a much simpler task). The use of a viewer is also a slight disadvantage. No equipment has yet been produced which will give adequate magnification and yet be reasonably portable, let alone pocket-size, though a portable viewer is not essential for use in libraries and offices. Libraries are using microfilms on an increasing

scale, and a complete record of all issues of *The Times* is available on film, also all English books in the British Museum written before 1500 A.D. Every one of the 10 million volumes in the Library of Congress, Washington, has been copied in this manner. Such reproductions when magnified serve the student just as well as originals, which are often irreplaceable. In the United States microfilm records are admissible in evidence and original documents so recorded can be destroyed.

The recording of information upon tiny films is not restricted to document copying, though it finds few other applications at present. It has been used fairly extensively for general record work in the form of "miniature photography". Cameras using 35 mm. film, pioneered by the Leitz Leica, have been used for many years by amateur and professional photographers because of their compact nature and the depth of field given by their small lenses. The negatives are similar in size to those records made by the larger document-copying cameras, and can be filed in much the same way. For this reason they are being used on an increasing scale, not only for copying small numbers of documents but also for recording buildings, equipment, experimental material and technical matter of all sorts, including views through instruments such as the microscope. They have also been used for factory personnel records and police records, though special cameras exist for this type of work. The small negatives produced by these cameras are simple to file in a very small space and yet capable of producing enlargements of excellent quality at a relatively high degree of magnification. It is the practice of many operators to produce a liberal number of record negatives for storage, making enlargements only from a selected few when required.

The field of document copying thus broadly described

has existed for a number of years, small improvements being introduced from time to time. Machines have recently been made available which will record simultaneously both sides of a double-sided original, thus eliminating the necessity for photographing twice. Photographic paper sensitized on both sides has also been introduced so that pages of bound volumes and other double-sided documents can be reproduced as they stand in the original. Micro-copying was widely used during the 1939-45 war for the Airgraph letter and V-mail systems. The need for quick communication overseas was accentuated by its effect upon the morale both of troops and their relatives at home. On the other hand, shipping was badly needed for other purposes. The use of micro-copies was the obvious solution, as thousands of letters could thus be flown by air in a short space of time, displacing only a minimum of freight. Over 1,000 million Airgraph letters were sent during the war.* Airgraph letters were written on specially provided forms, which were of a size to fit into the automatic document-copying camera. Each of the resulting processed spools of 16 mm. film was flown to the Airgraph station nearest its destination, where it was enlarged to a readable size on thin paper, folded, tucked into an envelope and delivered by the usual local postal facilities. The enlargements were made by a continuous enlarger in which the 16 mm. film travelled continuously in one direction above the lens, while the printing paper travelled below in the opposite direction.

A number of obvious trends are discernible in the development of document-copying methods. The direc-

* The principle of micro-copying was by no means new, for during the siege of Paris in 1871, Dagron made micro-copies of dispatches on tiny collodion films which were dispatched by pigeon post. On arrival a trained staff of artists reproduced by hand the images of the letters as projected by a lantern.

tion of most of these can be seen if one considers the ideal system which any office worker or librarian would prefer to use—a system which can be used in ordinary room lighting, dispensing with processing and providing a dry print without delay, also compressing the record into the smallest possible space in an economic manner. No such system has yet been invented or even approached, but lines of research lead in this direction. The factors at present limiting progress—and the recent developments designed to overcome them—fall into four classes: the degree of reduction in size, methods of handling and indexing the records, speed and ease of processing and the cheapness of the materials and equipment involved.

The amount by which the records can be reduced depends upon the resolving power of the optical equipment and of the emulsion used. Emulsions of high resolving power are always slow but this is not usually a great disadvantage in document copying because both intense lighting and relatively long exposure times can be used. This being so, emulsions capable of recording 25,000 or more lines to the inch have been evolved and a whole book can be recorded on a square inch of such material. Special lenses have to be employed to achieve such reduction, however, and have to be set with a precision which is impossible outside a laboratory. Moreover, if emulsion space is not to be wasted, the images must be spaced apart over the square inch of material with very considerable precision. This entails the use of elaborate and precisely-constructed mechanical equipment. It might appear at first inspection that one square inch of material could be exposed simultaneously, but the degree of reduction required would be about 150 to 1, if not more, and the pages of the book mentioned above would thus have to be spread out on an easel over 12 feet square to be

condensed into one square inch. Apart from the mechanical difficulty of performing such a feat, no lens at present available will reproduce the required detail over so large an area. Emulsions of extremely high resolving power are therefore mainly used at present for making fine grids and graticules for use in instrument eyepieces rather than for document copying. Nevertheless, they exist ready for the day when the necessary equipment is evolved. Such emulsions proved of considerable use for getting messages past enemy censorship during the war, making it possible for a communication of some length to be secreted under a detachable full-stop inserted in printed or written material.

The difficulties of handling materials in normal methods of document copying are of two types—firstly, the necessity for special types of lighting when making the records and, secondly, the mechanical problems of handling lengths of film. To the first, there is at present little sign of an easy solution. If a camera is used to make the records, artificial lighting on the document is necessary, though with modern equipment this need not be unduly cumbersome. Most library users would prefer to make a reflex print from a printed page, without using either special exposing lights or dark-room lighting. So far, such a project remains a wishful thought. Papers have been made which can be used safely in subdued room lighting but which are very fast to brighter lights. These operate because of the defect in photographic response known as “reciprocity failure”—a defect which makes a material slower at certain levels of light intensity than it is at others. In this case the defect can be turned to good use, but the technique as envisaged above remains a dream.

The mechanical problems created by the handling of various lengths of film have received more detailed

attention. A system has been devised whereby the film is driven through the viewer by motor, possibly to a pre-selected stop. In other cases, an indexing system has been recorded on the margin of the film. Such systems conjure up a vision (and it must be emphasized that it is only a vision) of a complete information service on microfilm, where one need only dial or key a code number to view the screen image of every reference to the subject. The practical possibility of such a system is in fact doubtful, for such a piece of equipment would be a heavy item of capital expenditure, and yet allow of being studied by only one person at a time. A more practical suggestion is that of cutting the film records into single frames or small groups and mounting them on index cards which could be filed in the usual way or handled by mechanical equipment such as Hollerith or Powers-Samas sorting machines.

Systems for filing individual cards have led to the using of Microcards. These are paper prints made from microfilms by contact (or exposed direct) though the images on them have often been made smaller than those on the usual commercial microfilms. Library index cards are used to carry images of between twenty and 100 pages, together with indexing data. In this way, an article can be accommodated on a single index card, while a whole book need occupy only a few cards. The cards, moreover, contain the full original information and not mere abstracts. This system is sponsored in America by the Microcard Foundation, who have marketed two special readers as well as the equipment needed to make the cards. A small reader enlarges seven times and is designed for quick scrutiny. Closer examination is carried out on a larger reader at an enlargement of $\times 24$. The greater expense of making the original negative in this system is offset by the saving in cost when making a large number

PLATE III

Photographic tailoring. The customer stands for a few minutes on a pedestal wearing a "harness" of tape measure. Records of five different views are made simultaneously through mirrors. From measurements made on the photographs, analysed in a special calculator, the suit can be cut out and delivered without the need for a fitting.

Courtesy: Photo Metric Corporation

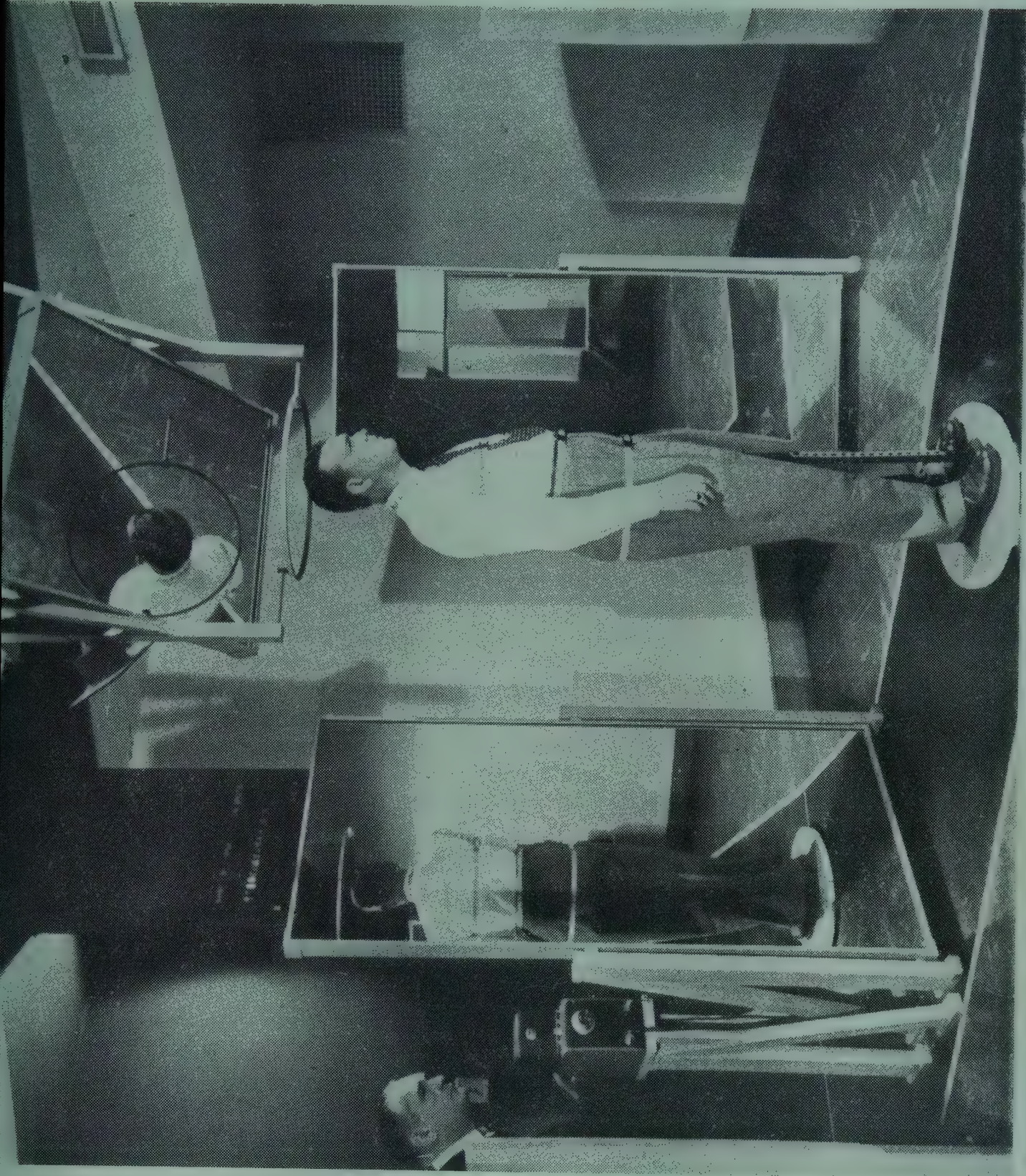




PLATE IV (a)

Courtesy: Kodak Ltd.

The photoelastic pattern in a cross-section of a railway chair and line. A model made in a transparent plastic (Catalin) was photographed in polarized monochromatic light. The pattern of lines shows the stress distribution produced as a result of the insertion of the key. The key itself appears black because it was made of wood, the steel components only being made of plastic in the model. Provided the elastic limit of the plastic is not reached, the stresses indicated by the patterns in the model are equally applicable to the steel parts.

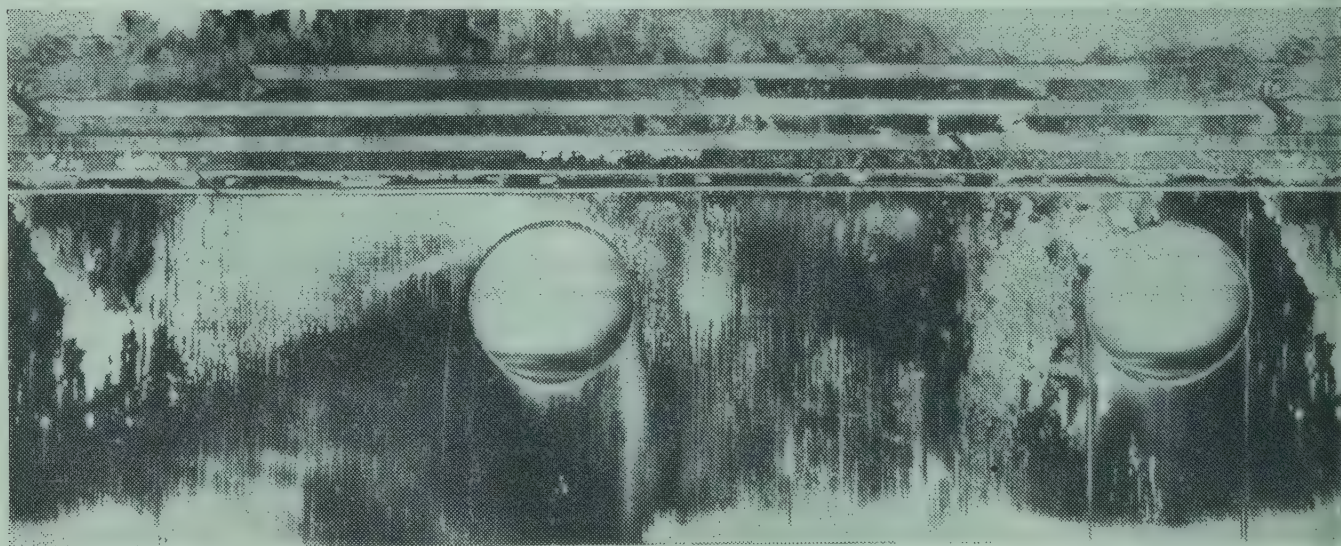


PLATE IV (b)

Courtesy: Shell Refining and Marketing Co.

A record taken with a special camera designed for recording the whole circumference of an internal combustion engine piston. The piston rotates on a table as it is photographed, thus "rolling out" the record on to a flat plate in the camera. Examination will show that the whole 360 deg. has been recorded in the record, the part of the piston on the extreme right of the picture being identical with that on the extreme left.

of prints. These cards are easier to file than conventional records, for they eliminate the need for possession of the original book or document concerned and can be distributed cheaply. The price per card depends upon the number made—prices quoted are twenty cents each for fifty copies or ten cents each for 200 copies. A somewhat similar system devised in Germany produces micro-books with the cards bound in book form. Some of these reproductions are not purely photographic, though they are produced from photographic originals by letterpress or lithographic printing.

Methods of processing have received considerable attention in recent years. Although conventional “develop, fix, wash” routine has become very firmly established, it is clumsy, lengthy and quite unsuited to the rapid production of dry records. A slight advantage may be gained by the elimination of the intermediate negative. “Autopositive” films and papers have therefore been introduced which will provide a direct positive by simple processing procedures.

It has been known for many years that combined developing-fixing baths were feasible, that short developing times were possible with certain formulæ and that fixing could, if necessary, be achieved by means other than dissolving the residual salts with sodium thiosulphate solution. Generally speaking, however, such methods of rapid processing were regarded as interesting novelties until the Second World War made their development a matter of importance. The U.S. Navy required photographs of radar screens to be processed in the quickest possible time and were therefore provided with a film which could be processed in hot solutions of special composition and dried by a blast of hot air. In this way, images of the radar screen, made on 16 mm. film, could be projected twelve seconds after exposure. A somewhat similar system had

been used in England before the war for a television system, but had not proved fully successful. The later American system does, however, provide some hope of a new basis for processing document records.

Similarly, two special printing papers produced for the Royal Air Force would seem to be of value in this field. One is on a waterproof paper base, which enables prints to be processed and dried very quickly, while the other is covered with a waterproof lacquer which permits exposure in contact with a wet unwashed negative. This lacquer, although quite impervious to fixing solution, is quickly dissolved by an alkaline solution such as developer and can be processed without difficulty. By using a paper combining a suitable selection of these properties it is now possible to produce numbers of copies of a document, on film or paper, in a matter of seconds. At present there appears to be no commercial equipment available for this purpose, no doubt due to the lack of urgent demand and the large capital outlay needed for such a pioneering venture.

Any method based upon such techniques would require elaborate equipment and it is doubtful whether it could be made portable or suitable for the production of only a small number of records. From this point of view, a considerably more significant invention is that of E. H. Land's one-step process. This enables a practically dry print to be withdrawn from the back of the camera within one minute of exposure, neither auxiliary equipment of any type nor solutions being needed. So far the process has been mainly adapted to folding-camera use for amateurs and general recording, but there is no doubt that the principle can be applied, with benefit, to document-copying devices.

This ingenious process is based upon the use of a supply of material consisting of two paper strips in rolls, one

coated with a fairly normal type of negative emulsion and the other with a non-light-sensitive layer capable of reacting chemically with the negative material. The two paper rolls are separate until the exposure has been made in the camera. They are then brought together between metal pressure rollers at one end of the camera back. Pods of viscous processing solution are attached at appropriate intervals along the non-sensitive strip and are broken as they pass between the rollers. Each pod contains exactly the right amount of solution to provide a very thin layer between the two coated paper surfaces over the area of one exposure. As the negative develops, it reacts with the non-sensitive layer, forming a positive image which is complete within one minute and can be removed from the back of the camera, the paper negative image being discarded. So little solution is used that the print is barely damp and dries almost immediately without cockling. As it contains no light-sensitive material it needs neither fixing nor washing.

Another specialized new process, which seems to offer scope for the provision of cheaper and easier document-copying systems, is Xerography, introduced by the Batelle Institute and the Haloid Company in America. In this process a metal, paper or glass plate is coated with a smooth layer of a semi-conductor such as selenium, sulphur or anthracene. It is then "sensitized" under safe-lighting by applying a high voltage electrostatic surface charge to this coating. The sensitized plate is then exposed in a camera or by contact behind a negative. The electrostatic charge leaks away in proportion to the light action, a latent image remaining in terms of an electrostatic charge. This is retained for a considerable period and can be developed by powdering the surface of the plate with a fine dry pigment. The resulting image can be

transferred to paper and rendered permanent by heating for a few seconds to a temperature sufficient to fuse the particles. A small machine has been developed along these lines for office-document copying. Such a method not only simplifies processing but should also be economic to operate, though it is at present in its infancy and further developments must occur before its place among other processes can be clearly defined.

The attempt to produce cheaper methods of document copying has also led to further work with diazo processes. These materials have been greatly improved for plan-copying work in recent years. Although they are not normally used for camera work, owing to their relatively low speed, they have been used by Van der Grinten for document copying by reflex printing. In the latest form, this Retocée process uses a plan-copying machine to expose a sheet of material through a flexible reticulate screen, which is stripped off and discarded after exposure. The resulting copy is used as a master for the more normal type of direct diazo printing.

Attempts to produce a diazo material of sufficiently high sensitivity to enable exposure to be made by means of low-power lighting have been disappointing, but a modified system known as the metal-diazonium process appears to offer considerable encouragement. This is based upon the power of the decomposition products of certain diazonium compounds to reduce metallic salts, thus giving an image in the metal. Thus if a mixture of mercurous nitrate and a suitable diazonium compound, coated on paper or any other suitable base, is exposed to light, the decomposition products of the diazo salt reduce the salt to mercury and a faint image is formed in this metal. This image is strongest where light action has been strongest and is therefore a negative, unlike the

normal diazo process. It is too faint to be used as it stands, however, and has to be intensified by a "physical" developer, i.e. by plating it chemically with another metal such as silver. Thus the material still requires wet processing, though it is about twenty-five times faster than normal diazo materials. It has extremely high resolving power—over 25,000 lines per inch—which makes it particularly useful for document copying. The contrast achieved can be varied by control of exposure duration and other means; it is possible to obtain very high contrast if required—again a most desirable characteristic for use in document copying.

The photographic document-copying field is, therefore, one of considerable interest. At present, two types of copying are widely used; one providing quick, cheap and accurate copies of written matter, plant or drawings on paper, usually in fairly large sizes, and another providing equally cheap, quick and easy reproductions in minute sizes on film for compact storage. The future will no doubt see a reduction of the equipment needed and the elimination of much of the dark-room work in use at the present time. Considerable funds of information may be stored or disseminated on small cards if suitable reading equipment can be devised.

As a final thought, it is worth considering the possibility of storing other types of information in this way. Apart from the large numbers of photographic records made by many technical and medical establishments, there are the thousands of radiographs, both medical and industrial, stored as historical evidence by many institutions and firms throughout the world. Although no accepted method exists at present for storing these in the form of micro-transparencies, there seems no reason why they should not be handled in this way, thus clearing acres of dry storage space for other uses.

SCIENTIFIC RECORDING

THE PREVIOUS chapter was almost entirely concerned with the recording of documents for storage purposes. Such an application is extremely useful, though somewhat uninteresting. No less useful, and of greater interest, is the application of photography to the recording of images, both for detailed and prolonged examination and for filing purposes. Visual observation is a fundamental feature of practically all scientific research. Photographic records enable such observation to be shared by many investigators and allow transient phenomena to be observed at leisure and with greater care. They also greatly extend the effective range of the eye.

The simplest form of such "scientific recording" (a poor expression used for want of a better) is the photographing at specified intervals of indicators which are not self-recording. Thus a series of pictures of manometers against a calibrated background, taken at hourly intervals, may save much tedious manual observation and recording. A particularly interesting example of this type of photography is the recording of Wilson Cloud Chambers, described in Chapter 9.

In the United States, telephone subscribers' accounts are often prepared from photographic records of the counters which indicate the calls made. These counters are recorded in panels, together with the date and other information, by means of a special camera, which includes a suitable illuminating device. Such records are easily

filed to provide evidence of the cumulative total number of calls made by individual subscribers up to a particular date. Another similar application is the recording of instrument dials in aircraft or other vehicles while they are in motion. Before the Second World War, Sir Malcolm Campbell used a small cine camera in the cockpit of his racing car "Bluebird" and in his speedboat to record the dashboard dial readings during trials and during actual record runs, on land and water. Since then, recording cameras of larger types have been devised for taking readings of many more dials over greatly extended periods of time. During the initial flight of the Bristol Brabazon about a thousand dials were recorded simultaneously at periodic intervals. An analysis of such a series of records can obviously give far more information than the written impressions of a large number of observers. Even on a much more modest scale, variables such as air speed, altitude, degree of bank, rate of climb, details of engine operation and so forth, can be shown with a fraction of the trouble that is involved in written records and with no possibility of error, under conditions which might make manual recording, or even visual reading of the dials, almost impossible. Several instances have been reported of recording cameras, salvaged from wrecked prototype aircraft, having provided valuable evidence of the cause of the accident.

Photography is of prime importance in collecting "evidence"—the word being used here in its legal sense—and is extensively used in forensic science. In police investigation it is often important to obtain clear records of the scene of a crime, and of objects connected with it, when such items and material cannot be retained for long periods. Good photographs enable indisputable evidence to be preserved and shown to the court or to

others connected with enquiries into the crime. Frequently evidence is presented in court with particular point and force when supported by photographs, while prisoners confronted with such material may be so convinced of the weight of evidence against them that they plead guilty.

Highly developed methods of photography are used to ensure that the photographs show their subject matter clearly and as the eye saw it. If care is not exercised, appearances can be altered to some extent by the use of special lighting, sensitive materials or colour filters, or by falsifying the perspective through the use of a lens of unsuitable focal length. In police work, such incorrect renderings are avoided by taking a number of records from different angles, often from eye-level, and deliberate accentuation of certain points is only resorted to when necessary. Motor accidents are usually recorded from several view-points, including shots made at eye-level from the direction of approach of each vehicle. In such records, skid marks often do not stand out clearly and these are therefore accentuated in special records made by the use of oblique lighting or polarizing filters. Detailed records of the damage are usually made, and similar close-up records of tyre marks on the road may often help to trace a vehicle which has disappeared after an accident.

Convicted criminals are always recorded in three views—full face and side face portraits and full length—under standard conditions of pose and lighting. Where photographs are available, they are often of the greatest value in tracing missing persons and identifying bodies. In recent years a technique has been developed for identifying skulls by comparing photographs of them with existing portraits of missing persons. If such portraits are available, recorded from different sides of the head, the “fit-

ting " of the skull to them, particularly noting the positions of the eyes, nose, ears and teeth, can provide very strong evidence of identification.

One of the best-known techniques is that of finger-print photography. Special cameras are used for this work, but good results depend much more upon careful technique than special equipment. Objects bearing finger-prints are first dusted with a powder to show up the prints. A black powder is used on light backgrounds and a white one on dark backgrounds; in some difficult cases a coloured powder may be used in conjunction with a colour filter on the camera lens. Good contrast of light and dark is thus obtained and clear close-up photography will provide records which can be critically compared with ink impressions from the suspect's fingers.

Another useful application is that of the examination of documents, to disclose forgeries, erasures and stains. Mechanical erasures can often be shown up clearly by photography under oblique lighting, while the comparison of two halves of a torn document enlarged by photography can prove that they fit together exactly. Handwriting which has been erased, additions to documents and writing on charred documents can sometimes be deciphered by photography under directional lighting which picks out the slight differences in reflectivity between the undisturbed surface and the area where the pen has scratched up the fibres. Similarly, oblique lighting will decipher the impression on underlying pages of a note pad of pencil or other heavy writing on the top sheet. In both cases the great accentuation of contrast made possible by photography can give a clear result when normal lighting alone produces an effect to the eye which barely renders the writing visible.

Critical examination of enlarged portions of a person's

handwriting enables forgeries to be detected and often discloses written additions made at a later date. Careful examination, by experts, of greatly enlarged portions of suspected writing, when compared with samples known to be genuine, renders the forger's work liable to a test so searching that it rarely escapes detection. In the case of alterations and additions, a comparison of the density and flow of the ink used and fuzziness of the edges of the writing will often enable the later date of the suspected portion to be easily verified. Superimposition of transparencies of two signatures can show whether one has been traced from the other; exact comparison of the two always suggests forgery, because nobody can write two completely identical signatures. Photography also aids the preparation of composite samples. In this technique, a phrase known to have been written by a particular person is copied by cutting out and assembling the appropriate letters cut from photographs of suspected documents, in order to establish that both the original phrase and the composite copy were written by the same person. This method is being increasingly used in tracing the senders of threats, blackmail demands, bombs in parcels, and so on.

These examples of police and forensic photography, however, merely touch upon the fringe of the subject. Many other techniques are employed which make use of infra-red, ultra-violet and other forms of photography. Some of these techniques are referred to in later chapters dealing with those specialized photographic methods.

Another specialized field is that of aerial photography, familiar to most people because of the widespread aerial reconnaissance carried out by both sides throughout the Second World War. Possibly less well known are the remarkable results which were achieved in this field by the

allied air forces, and the peace-time applications of aerial photography which have arisen from techniques developed during the war. These techniques depend primarily upon stereoscopic recording, dealt with separately in a later chapter. It is more than mere recording, because here again photography extends the range of vision of the eye by accentuating the appearance of depth.

Straightforward camera records are used extensively in industry, and among the many examples which could be quoted are the recording, by photography, of the construction of factories, of the erection and maintenance of plant, of damage caused in machine breakdowns, and of factory employees for the files of the Personnel Department. Other uses include the making of "still" records or films of methods of manufacture, individual processes and methods of assembling finished goods, records of raw materials such as silk or cotton for comparisons of "evenness" and "staple"; records of weathering and corrosion tests of paints, building materials, fabrics and metals. There is, however, no doubt that the widest use of photography is in industrial production departments and scientific laboratories where material is observed through instruments such as the microscope and the polariscope, and can be photographically recorded. Today photomicrography is of very great importance in almost every branch of scientific and industrial work.

Originally, the field of view under the microscope was painstakingly recorded by an artist specially skilled in such work. Artists specializing in this type of work still exist and their work is superb, often fulfilling a need where selection and interpretation beyond the powers of the camera are required. In the majority of cases, however, the quick and accurate record made by the camera is of greater value. The tendency in all branches of microscopy is for

the more cumbersome type of photomicrographic equipment to be used only when routine or specimen records are required. The microscopist usually has a smaller and simpler piece of equipment close at hand while he works, so that he can record immediately any particularly interesting observation. In some cases a miniature camera is used for this purpose, mounted on a stand which enables it to be placed quickly over the microscope eyepiece for a micro-film record to be made of the field of view. A record thus obtained is not always of such high quality as that obtained by more orthodox means, though the ease and speed of operation more than compensates for this. Complete photomicrographic outfits are also available, comprising a microscope, light source and camera all in one unit, and usually permanently installed in a cabinet. These are not intended for visual use, except in so far as the subject matter must be selected and the microscope focussed, but they allow the very finest photomicrographs to be made with a minimum of difficulty.

Equipment of this kind is most widely employed in metallography—that is to say, the recording of the structure and appearance of metal surfaces. Metal sections, smoothed and polished, show details of grain structure, segregation, porosity and other characteristics which indicate the strength, hardness and other properties of the material and the effect upon it of fabrication, annealing, cold working and fatigue. From such records crystallographers can also derive information on crystal form, growth and other properties of interest to them. By a comparison of such photographic records the theory behind the behaviour of metals has been patiently investigated and engineers and metallurgists have slowly assumed increasing control over the properties of the materials they use.

It is interesting to note in passing that photographic materials are also used by the metallurgist for purposes quite unconnected with their light-sensitive properties. Particles of sulphides in steel can be located by their chemical action upon silver salts. Hence, a sheet of photographic film or paper, soaked in acid, can be applied in broad daylight to the polished surface of a steel specimen and later stripped off with a clear brown "map" of the sulphide regions upon it.

Whereas the photomicrography of opaque specimens by light reflected from the subject is practised in metallurgy and petrology, most other branches of science are more concerned with specimens which transmit light. Photomicrography by transmitted light is largely practised in the important fields of zoology, botany and medicine. Here stained specimens are frequently used and photography can assist by accentuating the tonal differences between areas of differing colour or by clarifying detail in selected areas. There is, in fact, a very great difference between the casual record of a stained slide (which gives approximately the same effect in monochrome as that which the eye sees through the instrument in full colour) and a properly prepared photomicrograph designed to show some particular aspect of the preparation. Such a difference is typical of many branches of photography—almost anyone, with a minimum of tuition, can prepare a useful record, but the "expert" can produce results which demonstrate selected points even more clearly, particularly to the uninitiated, than does the original.

Another instrument with which photography is extensively used is the spectroscope. Most routine industrial spectrography is, however, now carried out with ultra-violet radiation and this is dealt with in a later chapter, together with the use of spectrography in astronomy. An

instrument perhaps not so well known as the spectroscope is the polariscope. Photographic materials react to polarized light in exactly the same manner as they do to normal light and they can usefully record the images seen in certain sorts of polariscope. The most important technique concerned is that known to engineers as photo-elastic stress analysis, which enables measurements to be made on stresses in mechanical components or architectural structures—stresses which would be very difficult to determine mathematically.

The method used entails the production of a scale model in a suitable transparent plastic, to which loads are applied while observations are made through a polariscope. In polarized white light the stresses in the model show up as coloured fringes: sharper black fringes are obtained in monochromatic light. These fringes immediately disclose the distribution of the stresses caused by any particular load, especially the points at which they reach a maximum or minimum. It is also possible to work out the magnitude and directions of the principal stresses from records of the patterns. The stresses determined will be the same regardless of the material used, provided the elastic limit of the test model is not exceeded and the real material is homogeneous. Hence the results derived from the model can be proportioned to apply directly to the full-scale object in metal or some other homogeneous substance. This technique is easy to use for two-dimensional problems and can be applied, though with greater difficulty, to three dimensions. It has been used with good results on many problems, such as the effects of fine surface scratches on highly loaded parts of car engine connecting rods, stresses round keyways in shafts subject to torsion and stress distributions in the spokes of wheels, in railway lines and chairs, gear teeth, the threads of bolts, pressed metal structures, plywood

panelling, aeroplane wing parts, and in cantilever bridge components.

Another typical use of photography in connection with a very uncommon instrument is its application to the bore-hole recorder—a piece of equipment used to determine the inclination of well bore-holes in the earth. The bore-hole recorder consists of a cylinder, slightly smaller in diameter than the bore-hole, which can be lowered into the hole while remaining orientated along its axis. Inside the cylinder a transparent compass dial is pivoted so that it will indicate the points of the compass no matter what position the cylinder assumes. Immediately below this dial is a piece of photographic material; above it hangs a small plumb-bob, suspended from the centre of a translucent disc or “roof” behind which is a pea-lamp bulb. When the cylinder has been lowered to the bottom of the hole, the bulb is switched on for long enough to expose the paper.

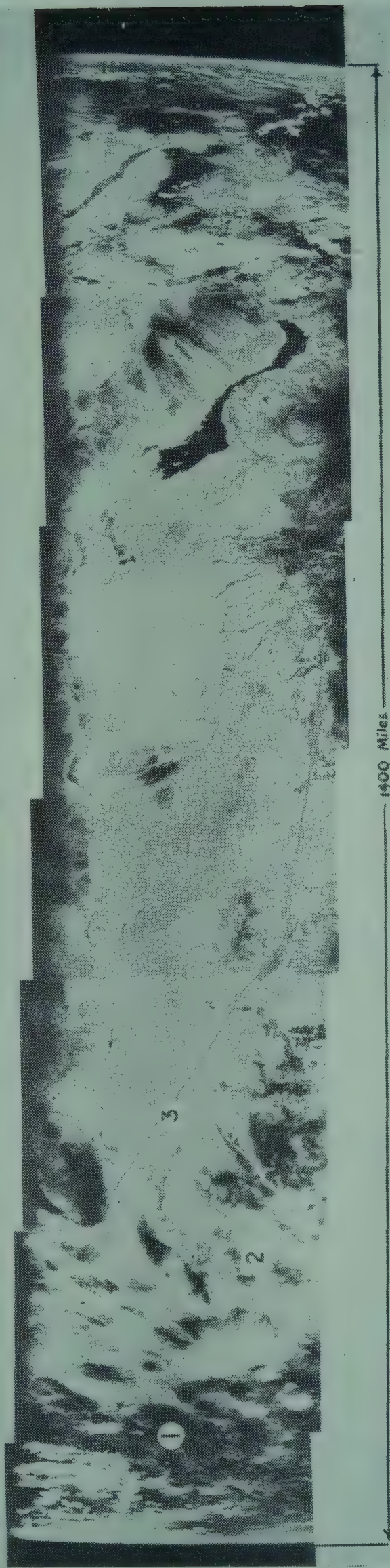
When the unit has been hauled up, the paper is processed and the resultant image shows a silhouette of the compass dial, with the shadow of the plumb-bob on it. When the hole is truly vertical, this shadow will be central. If the hole is at an angle to the vertical the shadow will be offset. The amount of this displacement gives a measure of the angle of incline, while the point of the compass to which the shadow is displaced shows the direction in which boring is being carried out. In this way, the bore-hole can be traced and its direction controlled so that cap-rock or other undesirable strata can be avoided and the boring directed precisely where it is required.

Photography can assist mining engineers and geologists in many other ways. One modern method of detecting the depth of certain strata is by echo-sounding. An explosive charge is detonated at a suitable point on the

surface of the ground and the echo, reflected from the strata below, is picked up by a series of sensitive geophones or seismometers at ground level. These geophones are all connected to a central recording van in which is housed a multi-channel oscillograph and a recording camera which enables all the oscillograph traces to be recorded side by side on one length of paper or film. This record shows the " pips " produced on each trace by the ground wave from the explosion and by the wave reflected from below. By converting this record into terms of path-length, the depth of the various strata can be calculated. This seismograph or echo-sounding method is widely used in oil prospecting, where distinct and well-known formations in the rock strata are sought as an indication of the presence of oil. This method eliminates expensive and tedious drilling except in areas where oil is most likely to be found.

Oscillographs are used in many other fields. Originally mirror or string galvanometers were used to modify a light beam from a lamp so that the record it made on photographic paper would form a measure of the galvanometer reading. Such types of oscillographs are still widely used for many purposes, though they have been supplemented, and in some fields largely supplanted, by the cathode ray oscillograph.

Mirror galvanometers are fairly widely used for recording small changes in the electrical characteristics of equipment, especially where a number of variables need to be recorded simultaneously. It is often easier to employ a number of small galvanometers than single- or multi-beam cathode ray tubes. Each galvanometer mirror projects a pencil of light on to a moving band of photographic paper and thus traces its course without any mechanical friction between paper and pencil. Such an arrangement is



Courtesy: United States Navy—Official

PLATE V

Two mosaics of aerial photographs, one of which shows about one-tenth of the earth's circumference. The upper composite was made from a V-2 rocket sixty miles above New Mexico. It shows part of Mexico (1), the Gulf of California (2) and the Rio Grande River (3), covering a sweep of 2,700 miles. The lower composite was made from an Aerobee rocket at a height of seventy miles. It shows a strip of terrain about 1,400 miles long. Landmarks include Mexico (1), Texas (2) and the Southern Pacific Railroad (3).

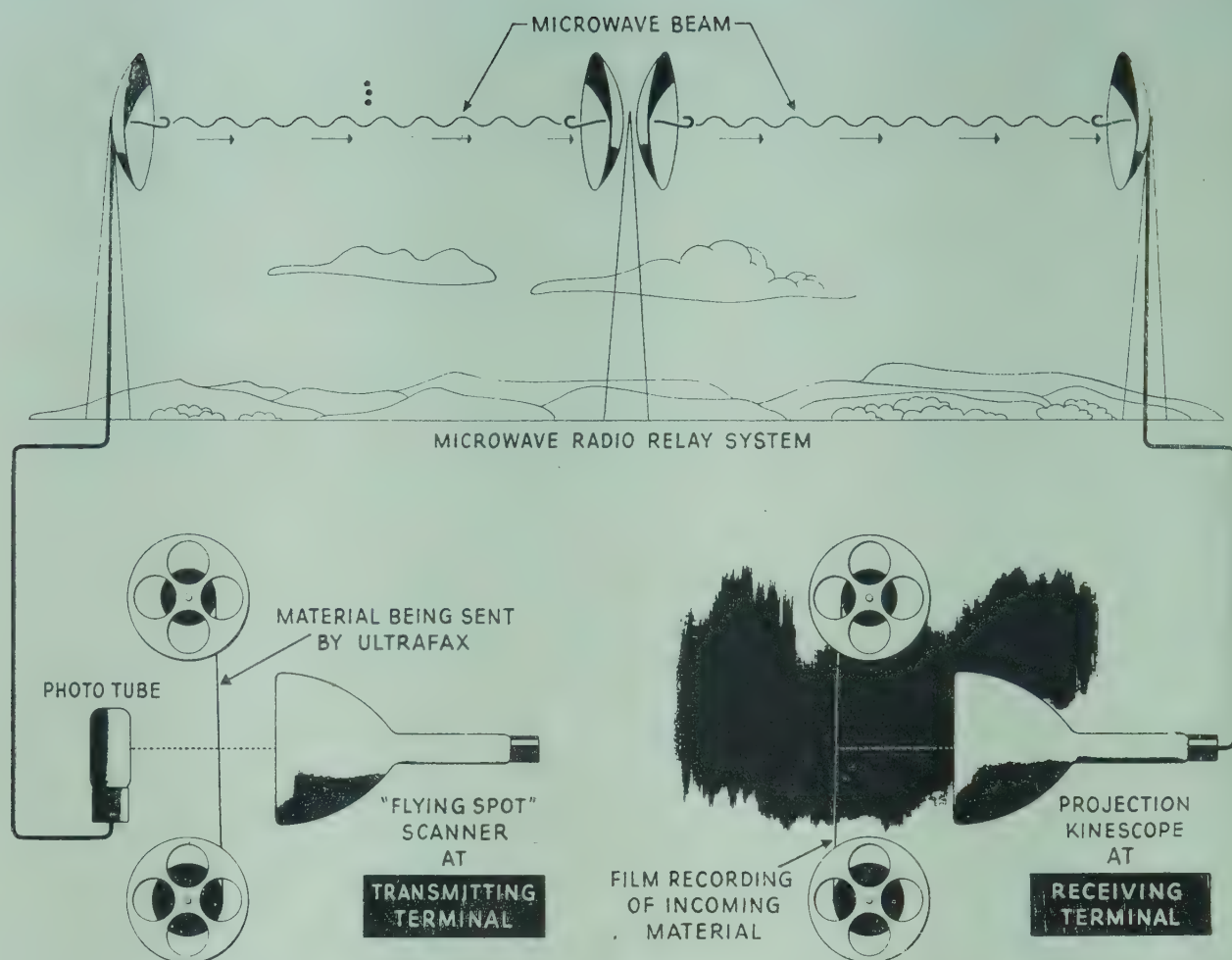
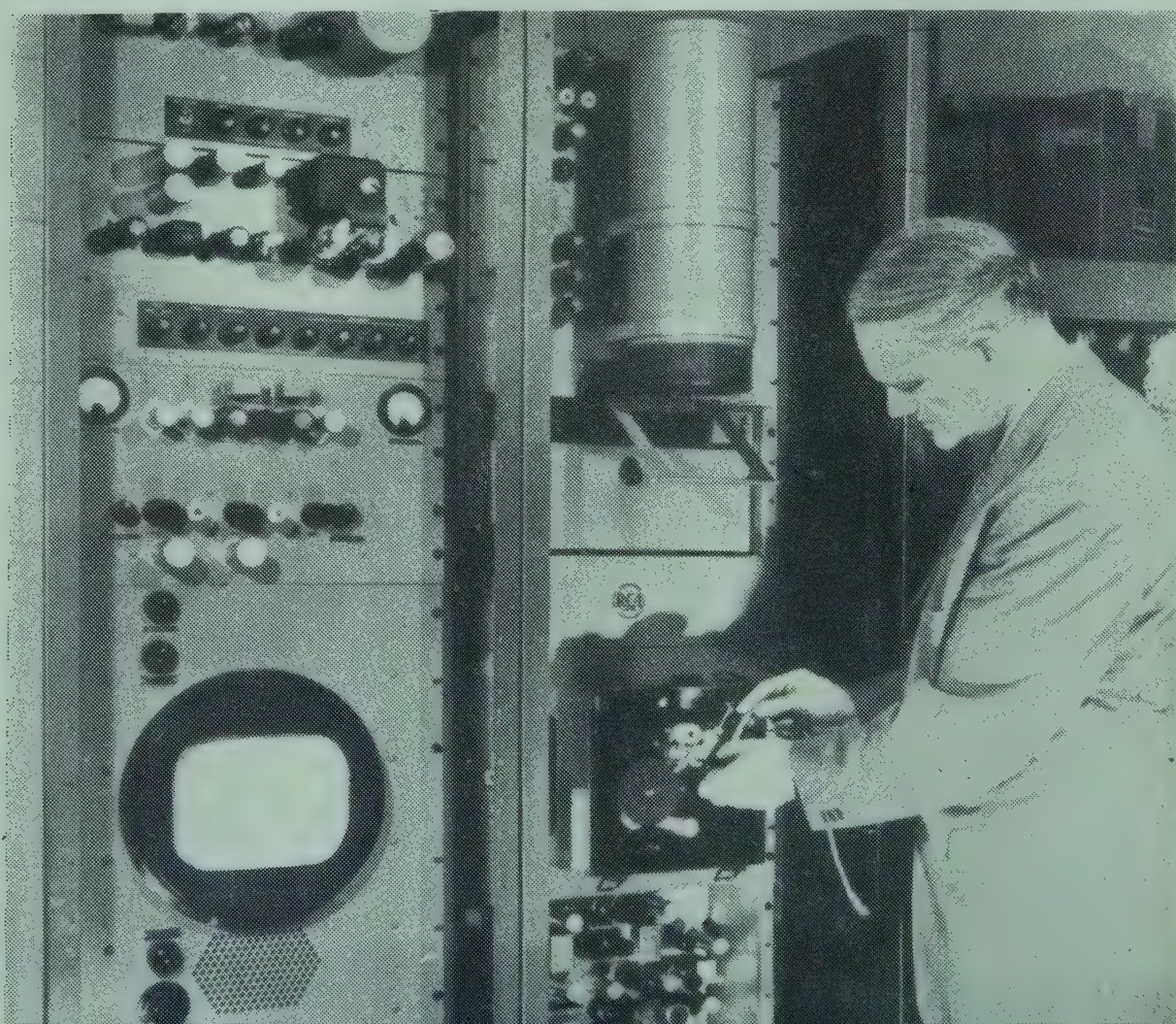


PLATE VI (a) and (b)

Courtesy: Radio Corporation of America

Diagram of the Ultrafax System for the rapid transmission of messages—1,000,000 words a minute, and below Ultrafax receiver incorporating the projection kinescope shown above. Exposed film is processed and dried in about 40 seconds.



employed not only for echo-sounding but for strain-gauge and similar applications. The vibration stresses in aircraft propellers can only be determined by electrical strain-gauges. These are small wire or carbon resistances which are firmly attached to, and move with, the airscrew blade. The gauges register slight variations in electrical resistance as they are strained, the change being proportional to the strain. The varying current flowing through the circuit containing the gauge is amplified and used to actuate a galvanometer. Thus the strain introduced by vibrations of the blade during rotation is measured. These strain gauges can also be produced photographically, as described in Chapter 10.

String galvanometers are used extensively in electro-cardiograph equipment and also in some geophysical recording. In this method a wire, vibrating between the poles of a magnet, casts a shadow in a beam of light projected on to the moving recording paper. This gives a white trace against the black background formed by the action of the steady beam. Such a galvanometer has proved suitable for use in portable equipment, especially for electro-cardiograph work in hospitals and consulting rooms, where the traces of a patient's heart-beats can be shown visually with a minimum of trouble.

Because of the adaptability of electronic circuits, the cathode-ray oscillograph is now the most widely used, although photography is not quite so easily applied to it. The electron beam inside the tube can be used to record directly upon photographic material, but as this must be placed inside the vacuum tube it is difficult to use a moving band of material. The more usual method is, therefore, to photograph the visible image produced by the beam moving across a luminescent screen, using for this purpose a simple external continuously-moving-film or paper

camera. Although the brightness of the screen is relatively poor, materials are available which, with suitable cameras, will enable writing speeds of well over 100 meters per second to be recorded clearly. It is unfortunate that there is considerable loss of efficiency at various stages in such a system, especially in converting the electron beam to light and in forming an image of the light pattern. Nevertheless, it would be extremely difficult to devise a method of recording cathode ray traces by any means other than that of photography, and suitable photographic materials can record practically all traces likely to be required on paper.

A particular form of recording which is of great importance in the entertainment of millions throughout the world is that of the sound film. Here a special type of oscillograph is used, which is vibrated by the sound waves received through the microphone coupled to it, and thus records a modulated band upon a strip of film. The actual record may be either of variable-density track (made by a modulated glow-lamp oscillograph) or a variable area track (made by a mechanical oscillograph which acts in a manner fundamentally similar to the string galvanometer). In either case, this track is outside the picture and printed near the edge of the projection copy of the film. It is used to modulate a beam of light falling upon a photo-electric cell which, in its turn, sends impulses to an amplifier feeding a loud-speaker, thus reproducing the original sound. The "speaking" clock used on certain telephone systems employs a similar method, using sound tracks recorded upon glass discs which rotate constantly, a process capable of infinite repetition with no loss of quality or wear upon the track.

Chapter 4

PHOTOGRAPHY BY DIM AND BRIGHT LIGHT

THE ABILITY of the photographic emulsion to integrate light over long periods may not seem of particular importance, yet almost all our knowledge of the positions, velocities and chemical composition of the stars is based upon photographic observation, which would be impossible if the photographic emulsion used did not possess this characteristic. The eye is quite incapable of perceiving any objects having a brightness below a certain value, no matter how long we stare at them. Photographic materials can, however, record such objects, provided that the total exposure is sufficient (exposure, to the photographic scientist, means the product of time and intensity). Hence a low intensity light can provide an adequate record if it is directed on to the emulsion for a sufficient time. This is not to say that the photographic emulsion is equally efficient at all levels of intensity. Its efficiency falls off at both very high and very low light intensity levels. As the intensity is reduced, so an increasingly excessive length of time is needed to compensate for it and provide adequate over-all exposure. The degree of inefficiency, or "reciprocity failure" as it is called, depends upon the particular emulsion used, some being better adapted to low intensity levels than others. This is the explanation of the proposed document-copying technique, mentioned in Chapter 2, which employs a photographic material virtually insensitive to dim white light but

usefully sensitive to the brighter lighting used for document copying.

Thus special emulsions have been produced for use where very long exposures are required. Their chief application is in astronomy, where photography has almost entirely replaced visual work. Observatories all over the world daily record the stars upon photographic plates. The fundamental purpose of this is to record the relative positions of all observed stars for future reference, in the form of an astrographic chart. As one complete star map of the heavens is completed another is begun, for the steady progress in astronomical technique makes stars of ever lower light intensity detectable for the first time and also enables their positions to be plotted with increasing accuracy. The pin-point images would be difficult to distinguish on the plate from dust specks if it were not for the use of double or deliberately blurred images, which represent each star as a small line. All the stars so represented appear as parallel lines. This is quite simply arranged either by a double exposure (to form a double image) or by ensuring that the mechanism which moves the telescope to compensate for the Earth's movement during the exposure is very slightly out of adjustment, thus elongating each star image into a short line. It is also common in astronomical work to record each star as a spectrum, instead of as a point image, which again differentiates it from a dust speck.

The number of stars visible in any photograph depends upon the duration of the exposure; a short time enables only the brightest stars to be recorded but after, say, ten minutes, all visible stars are recorded, and as the exposure continues, successively fainter ones appear on the plate until finally it becomes "fogged" by general scattered light from the sky. In this way a vast number of stars

have been discovered which have never been and may never be observed by the human eye. The light from them, which makes their record on the photographic plate, may well have started its journey over 10 million years ago. More and more is now being discovered about the composition of these stars and their movement, including evidence of the existence of stars as far distant as 1,000 million light years. The position of stars nearer to the Earth can be determined by parallax measurements made at intervals of six months, during which period the Earth has moved 186 million miles from one position on its orbit to the diametric opposite—a form of gigantic stereoscopic photography, giving the apparent shift between stars seen from the two positions, from which the necessary parallax measurements can be calculated.

In addition to recording the position of the stars, photographic observations have been adapted to measuring their “magnitudes”. To determine the magnitude of a star, the diameter of its image on a plate which has received a certain exposure is compared with that of a star of known magnitude, exposed for the same time on a similar plate. The size of the image, which is determined by the “scatter” in the emulsion layer, is a measure of the relative brilliance of the stars.

The spreading of the star's image into a spectrum by means of a prism gives considerable additional information. Spectrographic determination of the elements present can be carried out from the spectral lines recorded, as in terrestrial spectrographic analysis. Each element when heated produces light of a characteristic colour, the spectrum of which consists not of a continuous band of colours but of a large number of lines. Each line covers a specific wave-length range and there is thus a “line spectrum” characteristic of each element. To discover

the elements recorded in the spectrum of an unknown body, the wave-lengths of all the lines present could be measured and compared with the known values for all elements. As there are usually many lines to be compared, it is quicker to compare the spectrum of the unknown with that of a mixture of the most likely elements and pick out those which are present or absent.

Apart from the discovery of the composition of stars, spectra can be used for several other purposes. The characteristic line spectra of the elements are subject to distortion under certain circumstances, the lines shifting towards longer or shorter wave-lengths. Thus, when a heavenly body is receding from us at a high velocity, the light from it appears to be redder than it should be. The shift of the lines in the spectrum of the star is, therefore, a measure of the speed at which it is travelling and thus the photographic record can be used to determine velocities. Another example of shifting spectral lines, compared with the spectra of similar elements on Earth, occurs when the density of a star is abnormal. The greater the density of the star, the more the lines are shifted towards the red end of the spectrum. Some stars of extremely high density—the “white dwarfs”—have been discovered by this means. These are stars of high surface brilliance and mass which are, however, difficult to detect because of their very small volume. The density of some of these stars is so high that a cubic inch weighs approximately one ton. Without the technique of photography it would be very difficult to measure a star's density, but with this assistance, allied to the endless ingenuity of astronomers, new advances are constantly being achieved.

A classic example of this ingenuity is the method by which Einstein's Theory of Relativity was verified. One of the predictions made on the basis of this theory was that

light would be affected by a gravitational field. Thus a star positioned in the heavens so that it was just in view near the edge of the sun's disc should appear displaced from its actual position by the bending of the rays emanating from it as they pass the sun. During a total eclipse of the sun in 1919 a photograph was taken showing the stars in the vicinity of the eclipsed sun, some being very close to it. Comparison of this record with one taken of the same star field when the sun was more remote showed that the images of the stars nearest to the sun's disc were, in fact, displaced by the amount predicted from the theory. It is doubtful if this test could have been properly executed by any other means than photography, for the time of total eclipse would hardly be long enough to enable sufficiently precise measurements of star positions to be made in the numbers required for a complete record.

The ingenuity of the astronomer is aided by constant improvement in the quality of photographic plates. In cases where accurate measurements may have to be made and dimensional stability is of primary importance, the use of glass plates, with a firmly adherent emulsion layer, is essential. Research has provided better adhesion of the emulsion and materials of higher speed for long exposure times.

At the very opposite end of the scale is found the property of the photographic emulsion to react to light of high intensity. The eye is dazzled by extreme intensities, unless these are of sufficiently short duration to leave a mental image by persistence of vision. Below a certain limiting time no mental picture is recorded at all. The photographic emulsion also is only capable of recording at high brightness levels if the exposure time is correct, though no limit has yet been reached to the duration of such exposure.

A time of one-hundred-millionth of a second will allow a record to be made if sufficient intensity of illumination is available, and there seems no reason why shorter exposures should not be employed if they can be attained.

Here again "reciprocity failure" occurs, as it did during long exposure times, but in this case it is relatively easy to overcome by a fuller development of the emulsion, provided the material used does not exhibit a pronounced reciprocity failure. In any case, it is generally considered that there is no further falling away in speed below a certain exposure time ($1/100,000$ th second is the figure often quoted).*

The property of the photographic emulsion which permits the recording of high intensities is utilized in two quite different ways. The first is in the photography of objects of very great brilliance—such as furnaces, molten metals and explosions. The second, which is of far greater importance, is in the use of high intensity illumination to provide the extremely short exposure times needed to "freeze" movements of high velocity. The implications of this technique are immense, but the first type of application must be dealt with first.

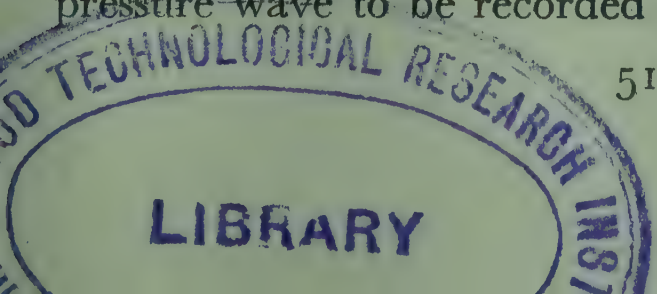
The use of photography in recording very bright objects is of considerable value. Although such objects can usually be examined visually if dark glasses are used (i.e. a piece of coloured or smoked glass or a "neutral density filter"), the camera gains over the use of the eye when the phenomenon is transient or in a state of rapid flux. In certain cases it can be used to measure or compare brightness, though its ability in this respect is strictly limited and must not be exaggerated. Most of the techniques recorded

* There seems to be some evidence that this is not entirely true and that if some reciprocity failure does occur at shorter exposure times it cannot be compensated for by prolonging development.

are concerned with the photography of arcs, explosion flames, furnace flames or hot metals.

Considerable work has been carried out in the examination of flames, and the ramifications of this subject are so wide that they are difficult to summarize. Fundamentally, this research has contributed much towards the solving of some problems of physics and physical chemistry. By the use of suitable records of flame fronts, the history of a gaseous explosion can be built up. Such records may be made up of multiple images superimposed upon a single plate or as a series of individual images in the form of, or similar to, a cinematograph film. In either case, very short exposures are usually needed to avoid blurring due to the movement of the subject, as well as to prevent excessive exposure of the material. Similar methods used in the recording of furnaces have been employed to study the burning of fuel (gaseous, liquid or solid) and the erosion of the refractory walls of the furnaces, while the fundamental physics of Bunsen and other burner flames have also been studied by use of such methods.

In the study of flame structure it is often important to record variations in pressure rather than in brightness. Although this represents a digression, it is worth while mentioning at this stage the method by which such a recording is made. The reason for including such information in this chapter is that the technique is normally used with high-brightness light-sources. The method is known as the Schlieren system and relies upon the change of refractive index of a gas when subjected to pressure or rarefaction. In its simplest form it consists of a photographic plate with a point source of light capable of emitting a sudden flash (e.g. an electric spark) in a darkened room. These are placed one on either side of the pressure wave to be recorded and the light flashed at the



right moment. For example, it may be desired to record the compression waves built up in the atmosphere by the passage of a bullet. The bullet is fired between the source of light and the plate, a spark being discharged at the exact moment the bullet passes. Apart from the shadow of the bullet on the photographic plate, there will also be recorded a clearly visible series of shadows of the major wave-fronts.

The reason for the series of shadows is not difficult to understand if the simple geometric optics of the system are considered. Most of the light rays will travel direct, along straight lines, from the spark to the plate, some being absorbed or reflected by the bullet and thus causing its shadow to be cast. Where a wave-front occurs, however, the air will be compressed or rarefied and its refractive index will be abnormal. This will cause those rays passing through this region to be deflected, and a shadow will thus be cast on the portion of the plate where they would otherwise have fallen. This principle is used to even better effect in the Schlieren optical system, which employs either a lens or a concave mirror to produce a similar effect. The Schlieren optical system is extremely sensitive—so much so that currents of warm air rising from a human hand can clearly be seen on a record, looking like dense black smoke. It has been extensively used in the study of gas flames, ventilation problems, cooling problems with lamps, carburation and evaporation, fan efficiency, and especially in aircraft design, for wind-tunnel research into aircraft and jet engine problems.

To return to the proper subject of this chapter, however, not only flames but electric arcs, furnace fuel beds and other objects of high brightness have been studied. Considerable information on the behaviour of electric welding arcs and gaseous welding and cutting has been obtained

from suitable photographs. The work poses considerable problems, however, because the brightness range of such subjects is greater than any photographic material can record. One must, therefore, either show the surroundings and cooler parts of the arc, leaving the bright core as a solid white area, or the surroundings as a dense black mass with the crater of the arc as the main feature. Very bright objects of this type usually lack contrast in their details, in spite of excessive over-all contrast. The detail in an ordinary record is apparent because of the minute high-lights and shadows cast on the surface of the subject matter by the lighting. But the luminous objects which we are now considering normally have no surface shadows because these are eliminated by the intensity of the light they themselves emit. In consequence they often assume a featureless appearance. Thus the record of a white-hot piece of metal or the inside of a furnace usually appears as an expanse of white or grey, with a minimum of detail. Any detail which is present is produced by slight variations in temperature caused, for example, by scale on the surface of the metal or variation in the combustion on the fuel bed.

Photography is therefore able, under such conditions, to provide an indication of the temperature of the various parts of the subject. Provided a body is hot enough to be luminous (i.e. above about 500° C.) its temperature can be measured by the brightness of the light it emits. At temperatures just above 500° C., only red light is available, but at high temperatures any colour can be chosen. At temperatures below 500° C., infra-red radiation can be used, and this is explained in detail in Chapter 6. Photography is not an ideal method of measuring brightness but with care it can be used with some success. The blackening of a photographic plate, after development, is an indication of the brightness of the object recorded.

The record may, however, be affected by numerous factors, such as the degree of development, the nature of the plate and the type of camera used. For useful results it is necessary to adopt a method of comparison of densities and this necessitates the inclusion in the record of patches of standard brightness alongside the object to be photographed. In the case of molten steel, lamp filaments have been found to provide a convenient standard, though care has to be taken to avoid random fluctuations in density from one part of the image to another. Under good conditions of test, temperatures can be assessed to an accuracy of plus or minus 3° C. at about $1,500^{\circ}$ C.

A similar technique has been applied to the recording and measurement of light distribution of lighting equipment, roads and the interiors of rooms. Though in these cases it is the illumination, and not the temperature, which is measured, the same method is used. Standard lighting set-up pictures are now regularly taken of new road illumination schemes to measure variations in lighting, which can then be plotted out on the records as contours. The principle is much the same as the astronomers' use of photography when comparing the "magnitudes" of stars. The astronomers are fortunate in being able to measure the relative brightness of the stars by comparing the sizes of their images rather than their densities. This is possible because for any one material the "spread" of a point-source image, caused by scatter among the crystals in the emulsion, is proportional to the brightness of the source. This is not true of extended sources and it is then necessary to measure the density of the negative image to assess the brightness. Astronomers sometimes determine star magnitudes by this method, using a micro-densitometer.

The use of photography for photometry is, however, full of pitfalls. As previously mentioned, it is almost

impossible to measure intensities by the amount of blackening they produce on the plate. It is only possible to compare an unknown with a known intensity, under carefully controlled conditions. Each standard lighting picture must, therefore, contain patches of known brightness to be used for comparison purposes, and must be developed with special regard to the factors which control the uniformity and consistency of results, i.e. composition of solutions, degree of agitation, temperature, length of development time, the material of which dishes or tanks are composed, and drying conditions.

Probably the most important application of photographic techniques employing very bright light sources is that known as "high-speed photography". This method uses the extremely short exposure time possible with very bright lighting to record very rapid movement. It is well known that a shorter shutter exposure increases the sharpness of a photograph of a moving object; press photographers use exposure times as short as $1/1,000$ th of a second to record fast-moving sports events. The reason for this is evident—the shorter the exposure time, the less distance the object covers while it is being recorded and the less blurring there is likely to be in the resulting record. Unfortunately, this simple answer to the problem of speed is not enough. The normal velocities encountered in ordinary life are relatively low and cameras can cope with them. But ordinary shutters are not suitable for the recording of high-velocity machine parts, of projectiles in flight or the faster human and animal activities. In such cases, much shorter exposure times are needed than is possible with any compact shutter yet invented. At the same time, if a mechanical device were available for giving such short exposures, normal lighting equipment would then be insufficient to provide an adequate intensity. The

shortest exposure which can be given of a near subject in bright summer sunlight with a wide-aperture lens is of the order of $1/10,000$ th of a second. Yet a bullet in flight cannot be recorded with an exposure longer than about a microsecond (i.e. $1/1,000,000$ th of a second). There is also the difficulty in triggering a mechanical shutter to catch such a subject—the lag in release is great (and often variable) by comparison with the actual exposure time. Finally, mechanical shutters are, as a rule, notoriously lacking in efficiency during short exposure times; i.e. the time taken to uncover and re-cover the lens or image area is at least as large as the exposure time itself.

These and other technical problems have been solved by governing the exposure time by the use of a short light flash of great intensity instead of by the shutter. A disadvantage of this device is that the method can be used effectively under subdued general lighting only, otherwise a background image will be produced during the time the camera shutter is open, which is, of course, much longer than the flash duration. Originally, an electric spark discharged from a condenser was used as a source of illumination. More recently the cold-cathode gas discharge lamp has been adapted for the purpose. X-ray tubes can similarly be designed to give short intense flashes of radiation.

An electric spark, however, can easily be made to give sufficient illumination to make a good silhouette record of a bullet, with an effective exposure time of about $1/1,000,000$ th of a second. This has the added advantage of making visible the shock waves produced by the passage of the bullet in the atmosphere, a result not possible of achievement with an extended source, such as a gas discharge lamp. Nevertheless, the gas discharge lamp gives a flash almost as short as the electric spark but with many

times its intensity; it is easier to control and employs auxiliary equipment which is more portable. Since Professor Edgerton of the Massachusetts Institute of Technology devised the first lamp of this type, many similar instruments have been designed. There are now units of all sizes, from giant aircraft assemblies for making aerial records of the ground at night, to small portable units carried over the shoulder for use with press and amateur cameras. Exposure times range from about $1/5,000$ th of a second to under one microsecond.

The analysis of movement is dealt with in all its aspects in Chapter 10. It is, however, sufficient to mention at this stage that these lamps make it simple to record almost any movement of man, animal, or machine. They completely replace the cumbersome and somewhat dangerous flash-powder outfit for recording events at night, though they have not yet displaced the modern enclosed flash bulbs, which give a higher intensity of light with a longer exposure time. They have the advantage, however, of being able to flash repeatedly for many thousands of exposures while each flash bulb gives only one flash and is then scrapped.

The advent of the high-speed gas discharge lamp has undoubtedly produced a revolution in the recording of moving objects. The electric spark has been used for many years as a means of illumination in scientific photography, but it is hardly suitable for general work, both on account of its relatively low intensity and the difficulty of building it into a compact and convenient portable unit. The gas discharge lamp, however, provides a handy source of light for almost any kind of indoor photography. It has greatly simplified the photography of animals and children; it has made possible a new type of portraiture in which the sitter can be "snapped" when his expression

is exactly right, without having to be concerned with movement during exposure; it has facilitated the clear recording in an easy fashion of such subjects as dancers, acrobats, and golfers' and tennis players' strokes; it has made press action shots at night simple and sure; and has enabled machine performance, the movements of machine operators and similar industrial problems to be studied easily and quickly.

One of the merits of the gas discharge lamp is the ease with which the flash can be triggered. Lamps vary in design but all produce the flash by the sudden discharge of a high-voltage high-capacity condenser through the tube, which contains a rare gas, such as xenon, under low pressure. This discharge occurs with very little lag after the circuit is completed. Although a reliable mechanical switch is difficult to provide for the voltage used (over 2,000 volts) it is usually practicable to employ an electronic switch. This has the double advantage of keeping the triggering lag short and of enabling a low-tension triggering circuit to be used, which can be actuated from a brushing contact, a microphone or a photoelectric cell. Thus a typical set-up for a commercial outfit of this type consists of a tube (coiled in a helix for compactness and held inside a frosted glass bulb) across the two electrodes of which is a 2,000-volt 30-microfarad condenser, charged through a transformer from the A.C. mains or from a battery with a vibrator. No discharge takes place until the gas in the tube is ionized by a pulse passed through a third electrode in (or wrapped round) the tube. A flash of high intensity lasting about $1/10,000$ th of a second is then almost instantaneously produced (the lag is probably of the order of a few microseconds). The third electrode is triggered by means of a thyatron or strobotron valve, which can be actuated by a voltage and current so low that they threaten

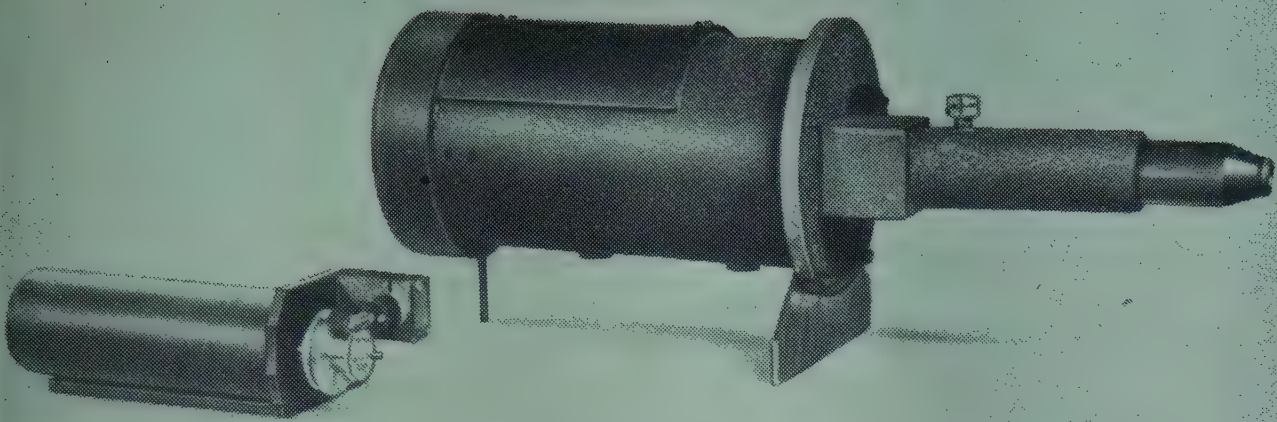


PLATE VII (a)

Courtesy: Eastman Kodak Co., U.S.A.

A spectrographic camera as used in stratosphere rockets to record the ultra-violet spectrum of the sun.

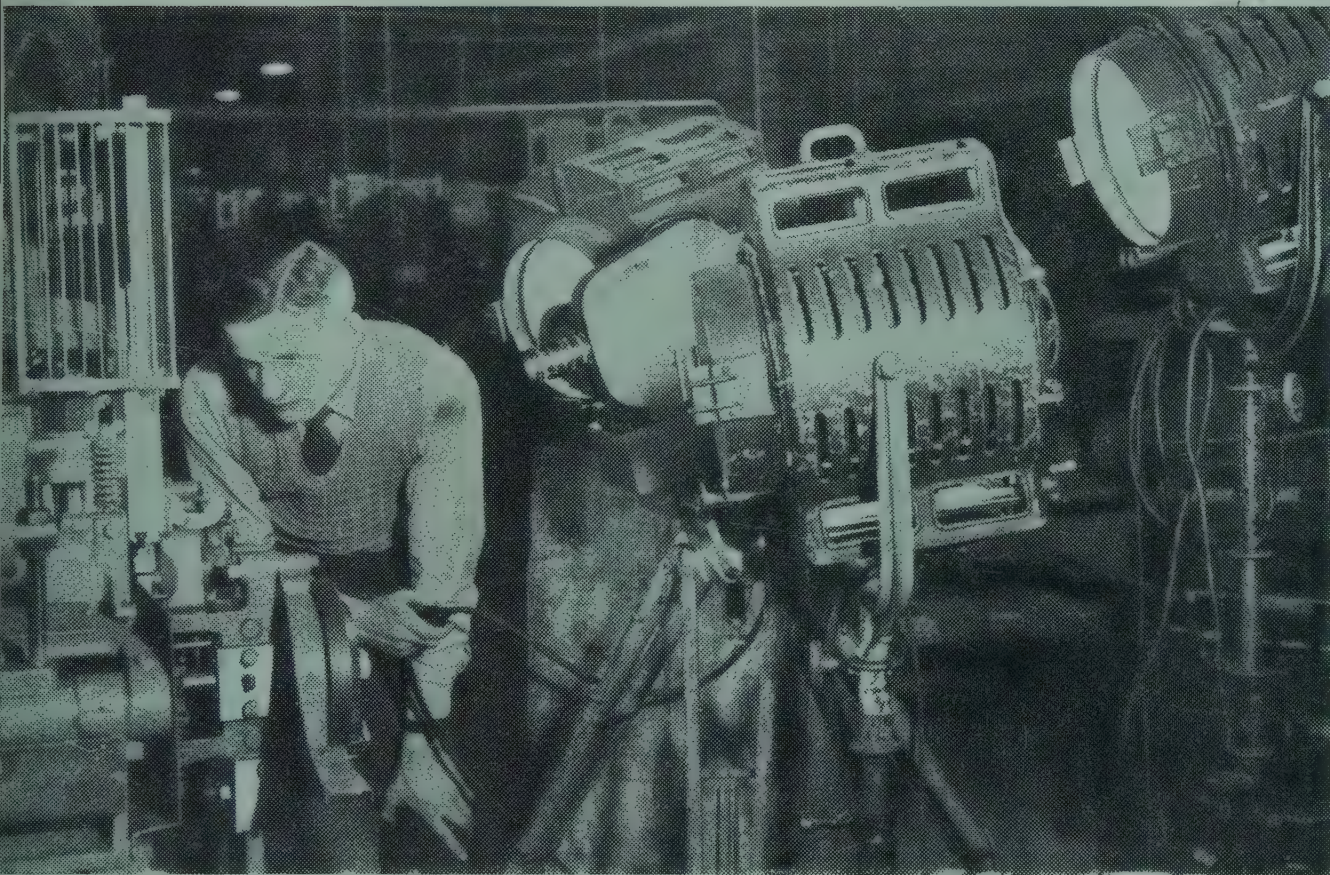


PLATE VII (b)

Courtesy: Kodak Ltd.

The Kodak high-speed camera in use on a machine. Illumination is provided by the three 2-kW. spotlights.



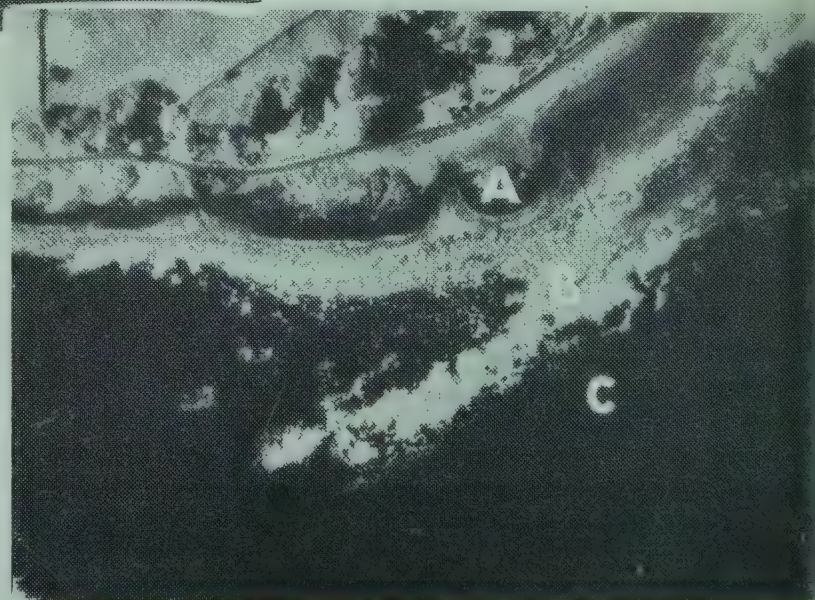
PLATE VIII (a)



PLATE VIII (b)

Detection of commercially valuable seaweed by making comparison photographs through a green filter and by infra-red. The former (above) shows a belt of probable rock weed (B) and a belt of bottom weed (C). Belt (B) is differentiated from rock and shingle (A) by the infra-red record (bottom), while (C) is invisible in the latter as infra-red rays do not penetrate more than a few inches of water.

Courtesy: Majors Wiggs and Conant and the Army Photographic Research Unit



(Above) Comparative aerial photographs of the same area of forest; (left) by normal photography and (right) infra-red. This technique enables certain types of trees to be differentiated (see legend in the centre): 1. White pine—new growth. 2. White pine—new growth. 3. Mixed white pine, hemlock and hardwood. 4. Hemlock. 5. Mixed hemlock and hardwood. 6. Hardwood.

*Courtesy:
Harvard Forest and Fairchild Aerial Survey*

no danger to even the most delicate forms of life. The condenser discharge itself is, of course, highly lethal and must be very carefully insulated.

As an example of this technique, the tongue action of a chameleon has been studied by wiring one side of the trip circuit to the animal's perch and the other to a metal plate on which a suitable bait was placed. As the long tongue stretched out and took the bait, it completed the circuit and triggered the flash. Yet the animal felt no shock through its body or tongue, as a current of only a few milliamps at two volts was needed to operate the trip circuit.

Lamps of this type have been available for only about ten years but they are already widely used in many branches of photography. Work is continuing in the production of tubes which will give shorter and brighter flashes of improved colour quality and in the designing of better circuits which require components of a lighter nature. These improvements are being utilized in many branches of research and may produce interesting results, though it is as yet too early to prophesy just what these results may be. Meanwhile gas discharge lamps are proving invaluable for use in connection with portraiture, press work, aerial photography, medical photography, document copying, scientific investigation of many sorts, analysis of athletes' movements, identification record photography and many branches of commercial and industrial work.

Chapter 5

RECORDING OF COLOUR

PHOTOGRAPHIC materials are now available which will record the actual colours of a subject, as opposed to merely rendering them in appropriate tones of grey. This natural-colour photography has been made possible by the introduction of panchromatic materials (i.e. plates or film using emulsions sensitized to the whole visible spectrum). It should not be confused with coloured photographs which, though often superbly realistic, are produced by the skill of the painter.

The first demonstration of colour photography was by Clerk Maxwell, who proved his theory using non-colour-sensitized plates, prolonging the exposures sufficiently to obtain the desired result. The older methods of colour photography involved the use of three separate plates, exposed in succession. Modern materials, however, avoid this triplication, though the principle on which they operate is the same. Before considering the applications of panchromatic materials it is desirable to explain the theory behind the method used. The potentialities and limitations of colour photography in its present form will then be more clearly apparent.

Clerk Maxwell showed how the visual impression of any colour can be built up by the suitable admixture of not more than three separate colours of light. It is important to realize that this is not a synthesis of the true colour itself. Thus a colour such as yellow (in any shade) can be matched by a suitable mixture of green and red light;

yet the wave-lengths involved bear no relation to each other—the yellow light may cover a narrow wave-length band somewhere between the red and green wave-bands, with no overlap whatever. The matching effect must therefore be based purely upon the colour-vision mechanism of the eye. This leads, as Maxwell showed, to the possibility of analysing any subject into its appropriate proportions of each of three primary colours and later combining these three colours in the same proportions to produce an impression of the subject in its original colours.

The original method was to make three plates of the subject through the appropriate red, green and blue filters respectively. The first filter recorded the proportion of red in each part of the subject, the second the proportion of green and the third the proportion of blue. If positives were printed from these plates and each placed in a lantern with the corresponding filter over the lens, three images could be projected in superimposition on a screen. These would build up the same appearance of colour as in the original subject.

Consider a red object on a black background. This would be recorded by the plate being exposed through a red filter, producing a black image on a clear background in the negative. Assuming the colour of the object to be a true red, it would not be recorded in any form by plates exposed through the green and blue filters, which would remain clear all over. Positives made from the three plates would, therefore, give a clear record of the object on a black background in the first case, and opaque slides in the second and third. When these positives are placed in their respective lanterns, the red light will throw an image of the red object, but the green and blue lights cannot pass through their respective plates,

hence the original appearance of the object will be accurately reproduced. Similarly, a yellow object on a blue background would be produced by transparent images with opaque backgrounds on the red and green slides and an opaque image with a clear background on the blue slide. White light is produced by a mixture of all three colours, red, green and blue; grey is merely white light at a lower intensity.

Although the above method has been used in practice, it is cumbersome and inflexible. Schemes have been devised for photographing all three negatives at once by using a beam splitter and combining the images after colour separation with the aid of a similar type of projector. Generally speaking, however, photographic prints are regarded as being more satisfactory than images which can only be seen on a screen. Thus modern development has proceeded along the lines of the production of paper prints or single transparencies. The latter method of recording is the main reason for present-day criticism of technical colour photography, for most users would prefer to have natural colour prints on paper. It is, however, far easier, at present, to produce good colour records in the form of transparencies, which have to be projected or examined on an illuminator. The reasons why this is easier are partly fundamental and partly due to the present limited stage of progress.

In order to produce a paper print, pigments or dyes have to be used. If the three chosen are complementary in colour* to the three filters used to photograph an original image, they can be deposited on the paper image-wise, by one means or another, to build up a colour picture. Unfortunately, the exact adjustment of the

* Complementary colours are any which together go to make up white light.

amount of each colour all over the image needs extremely careful control, and a very slight loss or excess of colour in any one part may completely ruin the record. The eye is extremely sensitive to tint—much more so than to density—and a minute difference in colour balance, produced by a visually undetectable density difference in any one colour, will often produce a quite inaccurate colour photograph. There are other technical problems which make colour print-making more difficult than it might appear. One of these is that the range of brightness available on paper is much lower than that of most of the subjects recorded—the brightest high-light can therefore only be as bright as the paper itself, while the darkest grey (i.e. the “blacks” of the image) will be as deep as the maximum reflection density allowed by the pigments or dyes. In monochrome photography the tonal scale can usually be adapted to give a good visual impression of the original scene, unless it is very brilliant, but in colour work the colour tints are easily falsified and it is seldom possible to indulge in this subterfuge to the same degree.

It must not be assumed from these rather pessimistic comments that good colour prints on paper cannot be produced. They can, but are difficult and expensive to make, almost impossible to produce in numbers with real accuracy in colour and are greatly influenced by the characteristics of the subject concerned. They are, therefore, more suitable for pictorial and advertising use or similar work, where the correct subjective effect is usually more important than the exact reproduction of the colours of the original image.

Although these comments are also true to some degree of colour transparency work they do not apply, at present, to the same extent. Most transparencies are the products

of integral processes. That is to say, the three filters are incorporated in the emulsion layer on the material and only one exposure has therefore to be made to effect the necessary analysis into the three colours. In some processes the filters lie side by side in a fine mosaic over the emulsion surface; in others three emulsions are used, each sensitive to one of the three primary colours and coated one above the other. In either case the material is processed as a whole. In this way it is easier to avoid variations between each of the three images. Intensive research work has produced dyes which are well suited to the processes and the final result can give a very accurate rendering. The problem of brightness range does not apply to the same extent with this type of material, as the brightness of the high-lights is determined by the background illumination, which can easily be increased, leaving only the density of the blacks to be controlled, which can more easily be done in a transparency than in a print.

Nevertheless, there are difficulties in the making and using of colour transparencies. The visual appreciation of a colour usually depends upon the surroundings in which it is observed, and it may be almost impossible to match by means of artificial light two colours which appear to match perfectly in normal daylight. Again, colour vision varies considerably between individuals, while a fair proportion of the population suffers from a variation in colour vision known as "colour blindness." Finally, if we remember that we are not really reproducing the original colours but merely a good visual match for them, the difficulty of the problem will be apparent.

The technique of colour photography is steadily improving, but there have been few applications of present methods other than those of a purely illustrative nature

and even these have been slow to develop. Advertising illustrations and records of intricate coloured objects, such as woven materials, have, however, been made in colour on a large scale. Attempts have also been made to record specimens of subjects which are of an ephemeral nature and considerable success has been obtained in this direction by photographing flowers, fungi, butterflies and fishes, though it has proved impossible to rely upon the accurate recording of some subtle and "sensitive" colour tints. In recent years colour has been increasingly used in connection with photomicrography, for recording both metals and translucent specimens. In the medical and biological fields good records can be obtained fairly easily of stained specimens, though some delicate tints may again be hard to reproduce. However, the heat-tinting of metals and specimens containing matter of varying colour can be recorded quite well. Other applications include the recording of fading tests on paints, of clinical skin conditions, photoelastic stress patterns and other examples of birefringence, and of cathode-ray tube traces where different coloured screens are used to differentiate between overlapping patterns of traces. On the other hand most attempts to record fluorescence and pale coloured flames have been none too successful.

Meanwhile, research continues and both materials and techniques are being steadily improved. The principle of the integrated processes is being applied to paper print-making, in the hope that better colour prints will be more easily available. The problem of making numbers of identical colour prints or colour transparencies is also being tackled, and its solution will be of particular benefit to those wishing to illustrate reports and documents produced in small numbers.

INFRA-RED SENSITIVITY

THE ABILITY to sensitize photographic emulsion to the infra-red portion of the spectrum has received possibly wider publicity than any other aspect of technical photography, and, as often happens in such cases, the possibilities have sometimes been greatly exaggerated. Infra-red photography has, however, many important applications. Before dealing with these, it would be helpful to review the facts about ordinary infra-red sensitized materials.

The portion of the infra-red spectrum to which photographic emulsions can be sensitized is very small when compared to the enormous range covered by the infra-red band as a whole. Materials suitable for use under normal photographic conditions cover only a short band just beyond the farthest visible red. Experimental materials are made which are sensitive for some way beyond this range, but they need prolonged exposure and are decidedly more difficult to handle than the usual materials. There is, however, no question of the sensitivity of any of these materials extending to the "heat" region of the infra-red spectrum, the wave-lengths of which are of a lower frequency. The sensitizing dyes used in some of the experimental materials are rather unstable and to prevent rapid deterioration such plates are kept in a refrigerator. Thus many people assume that these materials are sensitive to heat rays. This is not so, for the wave-lengths of heat rays encountered in everyday life are far beyond those to which any emulsion can be

made sensitive. All photographic materials become unstable with a rise in temperature, but retain their properties longer under cold storage; infra-red materials are rather more susceptible than others to changes of temperature.

All infra-red sensitive materials are also sensitive to white light. Some are panchromatic materials whose sensitivity extends beyond the red, while others are relatively insensitive to the green, yellow and orange bands. In either case, true infra-red records can only be made by covering the camera lens with a visually opaque infra-red filter. This prevents the wave-lengths in the visual portion of the spectrum from reaching the plate and ensures that any record so produced is by infra-red radiation only. As sunlight and all tungsten-filament lighting contains a high proportion of infra-red radiation there is no need for special lighting units except under unusual circumstances.

The value of infra-red photography lies in the difference in behaviour between this type of radiation and that to which the eye is sensitive. As the wave-length of radiation increases it is less easily scattered by small particles and its penetrating power is correspondingly increased. Infra-red rays are, therefore, less scattered by small water droplets and other particles than is white light. Furthermore, materials may absorb and reflect infra-red rays in a different manner from that of white light. Thus, objects recorded on an infra-red material usually undergo a change from their accustomed visual appearance. This is easier to understand if the following examples are considered.

A considerable number of dyes are available for dyeing cloth black. Their purpose is to absorb as much as possible of the white light which would normally be reflected from the finished cloth. Some are more successful

than others, producing a deeper and more neutral "black", though all the accepted dyes are reasonably efficient in this respect. There is, however, no guarantee that they will react similarly to infra-red light; their behaviour to such radiation depends upon the place where their absorption bands cut off. It is, therefore, quite possible to take an infra-red photograph of a black suit and find that it is reproduced as grey or even white. In a collection of pieces of black cloth, some will probably remain black in an infra-red record, while others will appear white or as various tones of grey. The result is entirely dependent upon the characteristics of the dyes concerned. The same principles apply to pigments, though many dark pigments when recorded by infra-red radiation also produce dark-coloured results.

Similarly, objects often do not reflect infra-red radiation to the same extent as they reflect white light. The most common example of this is in infra-red landscape views, where all green foliage appears almost white, as if covered with snow. This effect is produced by the high infra-red reflectivity of chlorophyll, the green colouring in most vegetation. To the eye, chlorophyll absorbs all but the green component of the sunlight striking it, but it reflects infra-red radiation completely and thus appears as a white image on the infra-red plate.

The powers of penetration of infra-red radiation are best known when related to photography through haze. It has been stated that fog and cloud can be penetrated by use of infra-red radiation, but this is not strictly true. It is a well-known fact that red lights can be seen in mist at a greater distance than blue lights. The difference is not great, but it is noticeable. The benefit derived from the use of infra-red radiation is as great in proportion again. The actual result depends upon the average size of the

particles of mist in any particular case. If these are small in relation to the wave-length of the radiation used, then the degree of penetration will be relatively high, but if large, the rays will be scattered to a certain extent and penetration will be less. Generally speaking, the average particle increases in size depending on whether light haze, mist, fog or cloud are present. It therefore follows that infra-red photography is usually wholly successful in penetrating light haze to record distant views, is of some use when recording through light mist, but is of no real value in conditions of fog or for aerial photography through clouds. Its failure in the latter respects is, however, of little importance, for radar can now be used, far more effectively than any photographic method, for detecting obstacles in fog, or for charting the surroundings of ships and aircraft.

One other attribute of infra-red photography is of importance—its ability to make records in total visual darkness. This is limited by the fact that infra-red radiation must be present in such conditions, and it is not easy to provide this in sufficient intensity without allowing a small amount of red light to pass as well, which the eye easily detects.

It is popularly supposed that the infra-red plate can be used for recording under normal conditions of darkness, i.e. at night, or in caves. This is not the case, for no source of infra-red radiation is then present. But hot bodies, just below red heat, emit considerable “photographic” infra-red radiation and can be photographed or even used as sources of illumination, if prolonged exposure times can be tolerated. The fastest plates require an average of about half an hour’s exposure at a wide lens aperture under such conditions.

Having dealt with the fundamental principles upon

which infra-red photography operates, let us consider its applications. The least important and least widely used is that connected with photography "in the dark". Attempts have been made to catch burglars and set traps for the unwary by this application, but the subject presents many difficult problems. A similar method has, however, proved useful in studying audience reaction at lectures and in the cinema. For this purpose the normal room lighting is such that the slight visible glow from the infra-red illuminators passes unnoticed and snapshot exposures or even cine films can be made without undue difficulty. The same principle is adopted in eye examinations without causing discomfort to the patient—an interesting film record has been made of the way in which the pupil of the eye alters in size in total visual darkness, following the switching-off of normal room lighting. The same technique has also been used for recording psychic studies and séances.

The recording of hot bodies by the radiation they emit has proved its value in the examination of temperature distribution in furnace walls, electric flat-irons, engine cylinder heads and similar subjects. The resulting photographs show the part under examination as if it were red hot and temperature variations are apparent as changes in density. As in the technique of photographic photometry, mentioned in Chapter 4, it is much easier to show such temperature variations than to make actual measurements of the changes recorded. The latter can only be obtained by comparison with adjacent standards included in the record and then only if the most careful technique is employed.

The range of temperatures over which infra-red materials can be used is limited. Just below 300° C. the wavelengths emitted are of such low frequency that exposure

INFRA-RED SENSITIVITY

times become prohibitively long, while above the point at which a visible glow is produced (about 450° C. to 500° C.) there is little advantage, possibly even a disadvantage, in using infra-red plates rather than normal panchromatic ones. One of the few cases in which infra-red plates are unquestionably of value for work of this nature is in the detection of stars of little brilliance having a temperature so low that they are most easily recorded on infra-red plates.

The penetrative power of infra-red radiation has been put to a considerable number of uses. As previously stated, the value of this property in photography through mist is doubtful, but infra-red materials do permit the elimination of pronounced haze which normally appears in records of distant landscapes, often with excellent results. The technique has been used successfully in aerial photography, where ground haze sometimes reduces the contrast of detail in normal photographs to such an extent that correct interpretation is difficult. The same method of application is used in recording distant landscapes, especially in mountainous areas, and for geological or other surveys. The results achieved with this technique appear to be much better in country districts than in towns, probably because of the high smoke content of the haze in urban areas. Carbon absorbs infra-red radiation strongly and smoke particles, which contain carbon deposits, are often of comparatively large size, thereby absorbing a large proportion of infra-red radiation. Infra-red photography has been used successfully to penetrate the haze inside industrial furnaces, enabling clear records to be made of the fuel bed or furnace contents.

Another use of infra-red radiation is in recording the subcutaneous conditions of the human skin, the layers of which are decidedly more transparent to infra-red than

to white light. Varicose veins, which are often covered by a layer of discoloured and coarse skin, can be examined more easily by the use of infra-red photographs, though the depth of tissue covering them which can be penetrated successfully appears to vary considerably with the characteristics of the patient and cannot be predetermined. Fair and delicate skin, when photographed, is sometimes almost opaque, while a visually more opaque skin may be penetrated to a useful extent. Similarly, changes in the subcutaneous venous system resulting from thrombosis or some forms of tumour can easily be observed. In lupus cases the lesion is covered with a scab, which obstructs the view of the healing process beneath. This scab is transparent to infra-red radiation, the use of which enables the clearance to be seen. Infra-red radiation has also been applied to the study of the eye, and in some cases where the cornea has become opaque, infra-red can be used to examine the iris.

Some materials which appear totally opaque to the eye are transparent to infra-red radiation. This is illustrated by the infra-red filters used over the camera lens, which allow almost all the incident infra-red radiation to pass, although the denser types of filter barely allow the eye to observe the sun through them when held up to it. Many visually opaque plastics react in similar fashion, provided that they are not "loaded" with carbon, or some other substance which absorbs infra-red radiation. Leather and a number of different kinds of wood are also relatively transparent to the radiation. For this reason, cameras used for infra-red photography must be carefully chosen if the plates are not to be "fogged" before exposure. Metal cameras with bellows dressed with carbon black are quite satisfactory, but wooden cameras with worn cloth or leather bellows must be treated with

considerable caution and carefully tested before use. Some of the older types of shutter were fitted with vulcanite blades which were transparent to infra-red and therefore useless. Modern shutters are usually fitted with metal blades.

Photomicrographs recorded by using infra-red radiation may enable structure to be observed in sections of wood where the use of white light would entail very long exposures and where the use of thinner sections is not practicable. This technique is of even greater value in the examination of insects whose exterior covering contains chitin. This horny substance (forming the exterior covering of cockroaches and beetles) is almost opaque to the eye and makes examination by microscope difficult. It can be made partially transparent by vigorous chemical treatment, but this often destroys the structures to be examined. The use of infra-red radiation does, however, enable insects to be examined clearly without destroying any part of them, and can be employed even when the insect is alive.

It is also possible by this means to differentiate between substances, all of which are opaque to the eye but which transmit infra-red radiation in varying degrees. For example, recordings of opaque plastics loaded with filling will show the efficiency with which the filler has been mixed, the positions of cores, linings and internal assemblies. This method has also been used for the examination of papers containing varying amounts of filler. A different application of the same technique is that used in the examination of documents. Some inks are transparent to infra-red rays, while others are opaque. Many cases have been recorded of an "opaque" ink used for writing having been obliterated by means of a "transparent" ink. Infra-red photographs then show the original writing almost

as if it had never been covered over. A famous instance was that of the manuscript of Theodore de Bry's *Travels in India* which was censored by the Spanish Inquisition, the passages to which they objected being heavily obliterated. These remained unread for 350 years, until, in 1932, Bendikson produced photographs in which the original writing could easily be read. This same technique is used extensively in detecting forgeries and alterations to legal and financial documents, licences and permits. Often two inks which to the eye match exactly can be proved to be totally dissimilar.

The use of photography in forensic science is of considerable interest and importance. Recording is not only by means of infra-red radiation but also by the use of ultra-violet and X-rays, together with many specialized techniques involving the application of photomicrography, spectrography and other scientific methods. Most of these will be dealt with in succeeding chapters, but at this stage we can mention some used in conjunction with infra-red techniques. They comprise most methods of recording for the examination of handwriting, typewriting and erasure of writing on documents. Examination of writing under the microscope will often show whether the original has been added to at a later date. Any disturbance of the fibres by mechanical erasure can often be detected, while photographic methods will show up the use of chemical ink eradicators. The handwriting expert examines the minute details of the style of writing in order to decide whether two documents were written by the same person. Often the easiest way of doing this is to make outsize enlargements which can be studied side by side and, if necessary, exhibited as evidence in a court of law. Sometimes a message written by some unknown person is compared with one of a similar nature

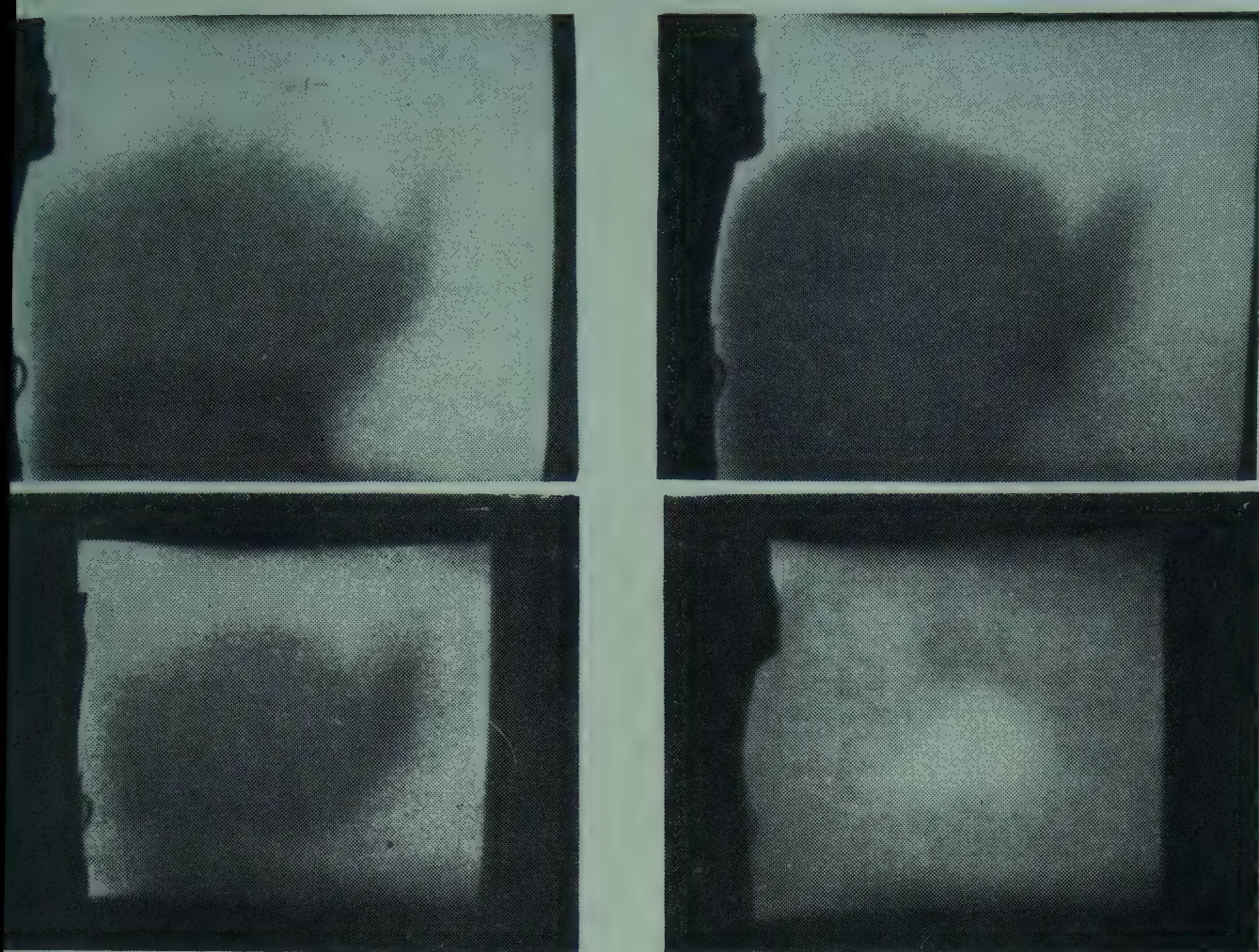


PLATE IX (a)

Courtesy: Eastman Kodak Co., U.S.A.

Photographs taken by thermal radiation alone, of a cooling kettle on an electric hotplate and (bottom right) a block of ice (see page 79).

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showing fine
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ntred carbide
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ble to the eye
the cutter was
rsed in oil and
nined under
violet radia-
The record
he cracks is
imposed upon
picture of the
cutter by a
le exposure.



ATE IX (b)

*Courtesy:
Research Labs. Ltd.*

Incas, Pa., January 23, 1932.

This is my will made this day because I am not well. I give all of my property of all kinds to my friend, Jacob C. Grustig. He is to settle my estate and can either sell the house or keep it as it is. I do this for Jake because he is my best friend and has done so much for me.

Signed.

L. V. Sarnoff

Seal.

Incas, Pa., January 23, 1932.

Dear This is my will made this day because I am not well. I give all of my property of all kinds to my friend, Jacob C. Grustig. *you* He is to settle my estate and can either sell the house or keep it as it is. I do this for *He* Jake because he is my best friend and has done so much for me.

Signed.

Jan 23, 1932

L. V. Sarnoff

Seal.

PLATE X

Courtesy: Eastman Kodak Co., U.S.A.

A forgery detected by means of ultra-violet photography. The top photograph shows the document as it appears to the eye. The lower one shows the image recorded by ultra-violet fluorescence: the signature is genuine but the original hand-written message above it had been deleted and replaced by the typewritten matter.

made up of a mosaic of separate letters clipped from documents known to have been written by a suspected person. A common method of forgery is for a forger to take a document with an authentic signature on it and insert above it the desired wording, either in place of, or in addition to previous wording. In such cases there is frequently little space available and the new matter so inserted may cross the older signature. Photographic methods may detect this but, if not, examination under the microscope can frequently show that the later ink was written over a dry signature, by disclosing the spread of the edges of the ink line. Often the characteristics of the two pens used can also be disclosed by such an examination.

Other applications in this field include the examination of hairs and fibres under the infra-red microscope, and the use of infra-red photographs for showing the structure of paintings. Photographic equipment is now an established feature of every large art gallery and museum. The penetration of surface layers of dirt, varnish and paint by infra-red radiation enables the artist's brushwork and any alterations to be examined more closely. Still deeper penetration for examination of the underlying layers is performed by soft X-rays. This facilitates the quick detection of forged paintings. The need for, and advisability of, cleaning can be easily determined and new information obtained about the great masters' techniques.

An entirely different application of the penetrating power of infra-red rays is based upon their inability to penetrate sea-water, a liquid which is visually fairly transparent. Aerial photographs have proved that the depth of shallow water can be gauged from the air by comparing the detail in submerged rocks and weed in ordinary photographs with those in records produced by infra-red

radiation. In very shallow water, both disclose the bed of the sea equally clearly, but as the depth increases the infra-red record rapidly becomes less clear until, at a particular depth, the bed can only be seen in the normal photograph. Deeper still, this will in turn lose detail.

The sea varies in transparency in various parts of the world and along each coast-line, but rough standards can be set for selected areas, indicating the varying depths seen in photographs taken under specified conditions. This method was used, with some success, in mapping the French coast-line before the Normandy landings in the Second World War. It has a peace-time application in carrying out seaweed surveys, for the various types of weed differ in their reflecting power to infra-red rays and can be picked out, both above and below water.

The group of applications which relies upon the varying reflectivity of materials to infra-red radiation is the largest and most important one. As mentioned in the last paragraph, apart from differentiating between surface and underwater growths by means of infra-red rays, some seaweeds can be identified from the air, for certain types which to the eye appear similar reflect infra-red rays to different degrees. This principle has also been extended to other types of vegetation. Although the green colouring matter in the leaves of all types of trees, known as chlorophyll, reflects infra-red radiation strongly, a number of different types of trees can easily be distinguished in infra-red aerial photographs. This is probably due to the other characteristics of the leaves and to the differing growth of the various trees. Even to the eye, the growth of conifers usually distinguishes the species, at a distance, from deciduous trees and the particular green of the foliage of a certain tree is often clearly distinguishable from that of another. Such colour variations are not always easy

to record in panchromatic aerial photographs, or even in colour records, but the use of infra-red photography in some cases actually emphasizes the different tones. This characteristic is of very great value in the surveying of timber resources, and for ecological investigations in regions where the terrain is inaccessible. It has proved its use in the survey of the great forests of Canada and Scandinavia.

In the early part of the Second World War it was thought that infra-red aerial photography might provide the answer in the detection of camouflage. The basis of this suggestion was the probable difference in infra-red reflectivity of paints and dyes, compared with that of vegetation, brickwork and other real matter. Although this technique was quite a practical proposition, it was only used occasionally, as the interpretation possible in ordinary aerial photographs proved to be so satisfactory that camouflaged areas could usually be detected by direct observation of unusual shadows, differences in appearance of the area under observation from day to day, the presence of paths to certain points and other signs of activity. It also proved possible, by making test infra-red photographs, to choose pigments and dyes to be used in the art of camouflage which were not susceptible to infra-red detection.

The selective reflection of infra-red radiation by pigments has been used in the printing industry to produce a "black printer". When carrying out colour printing it is usually necessary to reproduce greys and blacks by means of a separate plate carrying ink of a neutral shade, rather than by relying upon producing a satisfactory blend of the primary colours. There is, however, a problem in producing this plate. In photographing the coloured original, the normal separation negatives usually provide a good

record of the colours involved, the black printer being required merely for the neutral shades. Any normal photograph will, at the best, record the colours in terms of their brightness, the darker ones thus coming out as dark grey or black. Although this can often provide a reasonably satisfactory black printer, there are cases where the results are useless, the primary colours in the reproduction being swamped by the black printer. In this case the use of infra-red photography can be introduced. By choosing for the original art work pigments which reflect infra-red in the manner desired, the exact form of the black printer can be built up, the primary colours appearing as white, while the greys, blacks and any shadows appear dark. Such selection of pigments is often possible in advertising or where illustrations are produced to order, since the art work is normally specified before the work is commenced. If this is not possible, it is worth considering the effect of an infra-red record, for many coloured pigments strongly reflect this type of radiation, while all dark pigments containing lamp-black, and some others, absorb it.

Progress in infra-red photography has been continuous for many years, though there have been few spectacular advances. Originally, the sensitivity of materials extended only just beyond the far red, and very long exposures were needed. Gradually, research on sensitizing dyes extended the range of sensitivity until now there is an appreciable portion of the infra-red spectrum which can be recorded photographically. This is still very small compared with the total "heat ray" spectrum and it is doubtful whether photographic materials will ever be made directly sensitive to the longer wave-lengths. Improved emulsion-manufacturing techniques have produced very sensitive emulsions and ones which, at the same time,

deteriorate less under normal storage conditions. It is now possible to take an infra-red "snapshot" with approximately the same level of exposure and lens aperture as for a normal panchromatic record.

An important development has recently taken place, however, which appears to offer hope for the recording of the whole heat spectrum, in spite of the lack of a method of direct sensitization of the emulsion. This is known as thermography and employs infra-red sensitive luminescent substances to provide images which can be recorded by normal photographic means. Because luminescent substances always convert energy of short wave-length into that of longer wave-length and never the reverse, it will be impossible to produce visible luminescence by illuminating a body with infra-red radiation. Some "phosphors" which produce light when placed in the path of ultra-violet radiation have, however, been found to be very sensitive to heat. In other words, infra-red radiation will quench their luminescence to a greater or lesser degree. Work on these "phosphor" substances has produced remarkable results. It has been found that differences in temperature of as little as half a degree can be detected and that heat radiation from bodies at room temperature, or lower, can be recorded. The "phosphors" can either be painted on the surface to be examined or made in the form of a screen on which the "heat image" is projected by means of a concave mirror. In either case, the "phosphor" is irradiated, causing it to glow, while the heat rays from the surface examined quench this luminescence selectively. The resulting shadow image can be recorded photographically. In this way it has been possible to record a piece of ice as a bright area against a dark room-temperature background. A kettle of boiling water can easily be recorded, the result showing clearly the differences

in temperature between the bottom, the lid and the handle of the kettle.

Thermography opens up considerable possibilities in various fields of investigation and though it has not yet been developed to the stage where it can be used as a routine method, it has been employed for examining cooling systems and low-temperature heating devices. The technique offers the possibility of such advances as the examination of the spread of heat during welding and soldering operations, the study of the efficiency of heat insulation in domestic and industrial hot-water systems, and the observation of temperature effects in fabricating operations and on machines in motion.

Chapter 7

ULTRA-VIOLET PHOTOGRAPHY

ULTRA-VIOLET and infra-red radiations produce almost totally different responses in photographic emulsions. The emulsions are inherently sensitive to the ultra-violet spectrum, so that sensitizing dyes are not required to extend sensitivity into this region. Moreover, with certain reservations, emulsions can be said to be sensitive to some degree throughout the range of the ultra-violet spectrum, i.e. from the visible violet region to that where ultra-violet rays merge into X-rays. The reaction of the emulsion material to ultra-violet radiation is, however, less important than the power of photography to record the visual luminescence produced by ultra-violet radiation—for which no special material or technique is required.

Ultra-violet photography can, therefore, be divided into two distinct groups, one, making use of the radiation for direct recording and the other, employing the luminescence produced by ultra-violet radiation.

The first group, where the radiation is used for direct recording, necessitates the removal by suitable filters of all white light liable to affect the plate. Wood's glass, which is opaque to white light but transparent to the near ultra-violet rays, is a convenient filter material and can be placed over the camera lens or the ultra-violet lamps. Special lamps are needed to provide an adequate intensity of ultra-violet light which is present to only a very limited degree in the white light emanating from ordinary lamps. Mercury vapour lamps are ideal for this purpose as they

provide ample ultra-violet radiation over a wide range of wave-lengths. With shorter wave-lengths, below those transmitted by Wood's glass, ultra-violet photography becomes difficult owing to absorption of the ultra-violet radiation by the glass of the camera lens. Quartz lenses can be used but camera objectives made of this material are unusual and expensive. Microscope lenses, as used for ultra-violet photomicrography, are, however, smaller, and more easily available. At still shorter wave-lengths, the gelatine of the emulsion tends to become absorbent, though this can be rectified by the use of special plates. At such short wave-lengths the only application of the material is for spectrography. This application continues throughout the vacuum spectrograph region where ultra-violet radiation is absorbed by the atmosphere and about which relatively little is at present known. At the other side of this band is the longest wave-length (softest) X-rays region, dealt with in a later chapter of this book.

Most of the more interesting applications of ultra-violet photography can be grouped under the second technique, which is the recording of the luminescence produced by the radiation. This is obviously quite a different photographic problem from that presented by the use of the first technique, for now the actual record is produced with the aid of visible light of one colour or another. Ultra-violet radiation must not be allowed to reach the photographic material, for it may produce a greater effect than a feeble luminescence and thus spoil the record. The special ultra-violet lamps described earlier must still be used, again screened by a filter, e.g. Wood's glass, which allows only ultra-violet radiation to pass. The camera lens must, however, be covered by a filter which is visually transparent but screens off all ultra-violet radiation, allowing only the

ULTRA-VIOLET PHOTOGRAPHY

light from the luminescent object to pass. Filters made from various organic chemicals possess this property.

Those applications of photography which employ ultra-violet radiation for direct recording fall mainly into the same classes as the last two of those described in the chapter on infra-red photography. Thus, some objects reflect or transmit ultra-violet and white light in varying degrees, so that their appearance in ultra-violet records may differ appreciably from their true visual appearance. The applications of ultra-violet radiation are not nearly so numerous as those of infra-red, possibly because of the more difficult operating conditions involved. Many of the best infra-red applications make use of daylight when recording, whereas photography by means of ultra-violet radiation can only easily be carried on indoors. A typical example of the use of ultra-violet radiation is in the examination of the surface condition of white-hot metals. These do not emit any appreciable ultra-violet radiation and it is not possible for records to be made of them through a visually opaque filter such as Wood's glass, unless an ultra-violet lamp is used for illumination purposes. Their brightness prevents any proper examination of surface conditions by the naked eye and any roughness, scale or surface markings can only be observed from the light and shade produced by careful external lighting. This external lighting is normally swamped by the light emitted by the subject itself, whereas an ultra-violet lamp enables the specimen to be illuminated and photographed as if cold, revealing the true features of its surface.

Other applications of ultra-violet absorption photography include the recording of differences in inks, dyes, and materials, though the versatility of the process is much less than that of infra-red. There are, however, two main applications of quite a different nature and of

some importance. These are ultra-violet photomicrography and spectrography.

Ultra-violet photomicrography is used because it enables finer detail to be analysed than is possible with white light, and again because it distinguishes parts of living cells which cannot be observed by the naked eye. The shorter the wave-length used, the greater, theoretically, is the analysis of detail. Thus the use of blue light renders more detail at high magnifications than that of red, while the use of ultra-violet radiation increases the detail still further. Clearly, the shorter the wave-length of the ultra-violet radiation used, the better the results. In practice, however, this is limited by the availability of suitable sources of short wave-length ultra-violet radiation and the special optical equipment needed to apply this technique. Quartz lenses have been popular for many years but the mirror systems pioneered by Burch are now more widely used as they do not limit the range of available wave-lengths. The possibility of using this technique to improve the resolving power of the microscope has proved less attractive since the advent of the electron microscope, which gives still higher resolution of detail. The ultra-violet microscope is, however, a less expensive instrument and of unique value in the examination of living matter, for which the electron microscope cannot be used. One form of ultra-violet microscope commercialized in the United States of America is the Land colour-translational microscope. This ingenious instrument enables three different ultra-violet wave-length bands to be used in turn for three successive exposures, each negative thus providing a visual image in a different primary colour. By combining these a "pseudo colour picture" is built up, representing the ultra-violet response of the specimen as if it were recorded at a longer wave-band in the visible spectrum.

Spectrography, referred to in an earlier chapter, is concerned with the identification and estimation of chemical elements by means of a photographic record of the lines constituting their spectra, these lines taking up positions which are characteristic of each element. Many elements produce lines in both the visible and the infra-red regions, though it is fortunate that most metals show the largest number of useful spectral lines in that part of the ultra-violet region easiest to record photographically. The metal to be analysed is made into (or placed upon) electrodes, between which an arc can be formed or a series of sparks passed. The light so produced is passed into a spectrograph containing a photographic plate on which is recorded the ultra-violet spectrum against a wavelength scale. Comparison of the developed plate with a standard atlas of spectra, or with test spectra made from known elements (which, if necessary, can be photographed alongside the unknown spectrum, on the same plate), will usually determine the element or mixture of elements present. The concentration of each element in an alloy can be determined from the densities of the lines on the plate. These lines are very small and can only be measured by means of a micro-densitometer, an instrument for measuring the density of very small areas.

The technique is rather exacting and is not made easier by the difficulties which are inherent in all forms of photographic photometry, whether applied in spectrography, photothermometry or the study of scene-brightnesses. In this case it is the intensity of the ultra-violet lines which is actually recorded, the intensity being proportional to the concentration of the element concerned. As mentioned before, the difficulties can be overcome by using standards of known intensity (in this case corresponding to element concentration), which are recorded on the same plate, the

unknown specimen being measured by direct comparison with the known. The magnitude of some of the errors is rather less in ultra-violet spectrography than in other applications, owing mainly to the location of the image near the surface of the emulsion instead of at a depth, and this has made it possible to develop a reasonably accurate method of spectrographic analysis. Although care has to be exercised in the design of equipment, the processing of the plates, the measurement of the line densities and interpretation of the results, this method is considerably quicker in most cases than conventional chemical analysis. It also has the great advantage that it can be applied to minute quantities of material, producing a result often comparable in accuracy with that obtained by the more laborious and conventional methods. Spectrographic analysis is consequently being used increasingly in carrying out routine industrial analysis of alloys, both for the identification of scrap and for the control of batch quality. It has also proved of great value in criminological investigation, where minute quantities of matter have sometimes to be analysed or identified.

The development of spectrographic analysis has drawn attention to the problem of producing plates suitable for ultra-violet photography. All photographic emulsions are sensitive to ultra-violet radiation and in the early stages of spectrographic analysis workers used any plates which happened to be available. Gradually, it was found that some gave better results than others and, in particular, that high sensitivity to white light did not necessarily mean a correspondingly high response to ultra-violet. The contrast of many emulsions was found to be different in the ultra-violet and blue regions; and with all emulsions the contrast and sensitivity were found to be reduced in varying degrees at shorter wave-lengths. Emulsions

have now been manufactured which contain properties of particular value for ultra-violet spectrography. Some have a uniform and relatively high contrast over a wide range of wave-lengths, while others enable good results to be achieved within the shorter wave-length range.

The main difficulty experienced in recording at very short ultra-violet wave-lengths is that of the absorption of the radiation by the gelatine in which the silver halide grains of the emulsion are held. Another is that the response of the silver salt itself tends to be reduced. Both have been overcome by placing a layer of fluorescent material over the surface of the plate, which then records the resulting blue or green light, as well as any ultra-violet which penetrates the layer. Various types of fluorescent oils, greases and organic solids have been used for this purpose. The absorption of the radiation by the gelatine has also been overcome by the simple expedient of eliminating the latter, and various types of emulsions have been made either containing a minimum of gelatine or from which the silver halide grains protrude above the surface of the gelatine layer like stones in a flower-bed. The latest plates now available are reputed to contain no gelatine at all. These special plates are of particular value for experimental work rather than for routine industrial work, which is catered for by the more ordinary type of product. Nevertheless, the research tools of today are often the routine industrial instruments of tomorrow.

The recording of the luminescence produced by ultra-violet radiation has many applications. The most spectacular of these is probably to be found in forensic work. Many substances, including oils, some dyes and certain body fluids, fluoresce strongly, enabling contamination of clothing or other material to be easily proved. Paper also glows to a certain extent, a quality of great value in

assisting the detection of alterations to documents. The action on the surface of the paper by mechanical erasure or the use of chemical eradicators usually affects the degree of luminescence and the area disturbed can thus be seen. In some cases the original writing, which is invisible to the eye, becomes apparent owing to a slight local difference in the luminescence of the part of the paper originally covered by the ink. Alteration of water-marks can also be detected by the use of ultra-violet radiation. As in the case of infra-red examination, certain inks which to the eye appear identical may react quite differently to ultra-violet radiation, thus aiding the detection of insertions or alterations to documents subsequent to the original writing. Finger-prints are sometimes difficult to record, especially against a multi-coloured background, such as a lacquered surface or a coloured china ornament. Such objects rarely produce a strong glow and finger-prints can thus be clearly revealed against an apparently black background, by dusting them with a strongly luminescent powder, such as anthracene.

There are many corresponding applications in industry. One of these enables the distribution of grease over metal parts to be shown, thus giving information on its rust-protection properties or on the efficiency of de-greasing. A similar application has been used in connection with fabrics for determining both the distribution of oil dropping on to the fibres from faulty machinery and of certain luminescent dressing compounds. The technique has also been applied to detection of cracks in metal parts. The part concerned is immersed in a bath of solvent containing a fluorescent compound which by capillary attraction enters all cracks. When the part is taken out and the surface cleaned, the compound still remains in the cracks, and glows clearly in ultra-violet light. A photograph can

then be made by means of a double exposure, showing the cracks as white lines on the surface of the metal part, which is separately recorded by white light. Thus their exact positions can be recorded accurately in a manner not possible if an ordinary record were made, merely showing the cracks against a black background, with no indication of the metal part itself.

Bearing in mind the ease with which both types of ultra-violet photography can be carried out, it is a technique which has surprisingly few applications. Ultra-violet spectrography is important and its use is steadily increasing but most other existing applications are confined to the narrow limits of forensic science and research work.

RADIOGRAPHY

AT THE shorter wave-length limits of the ultra-violet region of the spectrum, about which little is at present known, the character of the radiation changes completely. The "vacuum spectrograph ultra-violet" band is so called because the rays are absorbed by the atmosphere and therefore can only be studied in a vacuum. Beyond this band, however, the radiation becomes steadily more penetrating as the X-ray region is reached. The penetrating power of X-rays is at its lowest within the longer wave-length limits, where the radiation is known as "soft" X-rays or Grenz rays, and highest at the shorter wave-length limits, where it is known as "hard" X-rays or gamma rays.

These various rays are recorded by means of photographic emulsions and practically all radiography is now carried out with the aid of photography, although if only a cursory examination is required, images produced by X-rays can be seen on fluorescent screens.

Photographic materials are inherently sensitive to X-rays of all wave-lengths. Their sensitivity varies with the precise characteristics of the emulsion used though it is not possible to impart special sensitivity by the use of dyes, as for the visible and infra-red regions. However, if required, greater effective speed to the rays can be obtained by the use of materials placed in contact with the emulsion surface, in the form of thin sheets or screens which fluoresce under radiation. It is normal practice to

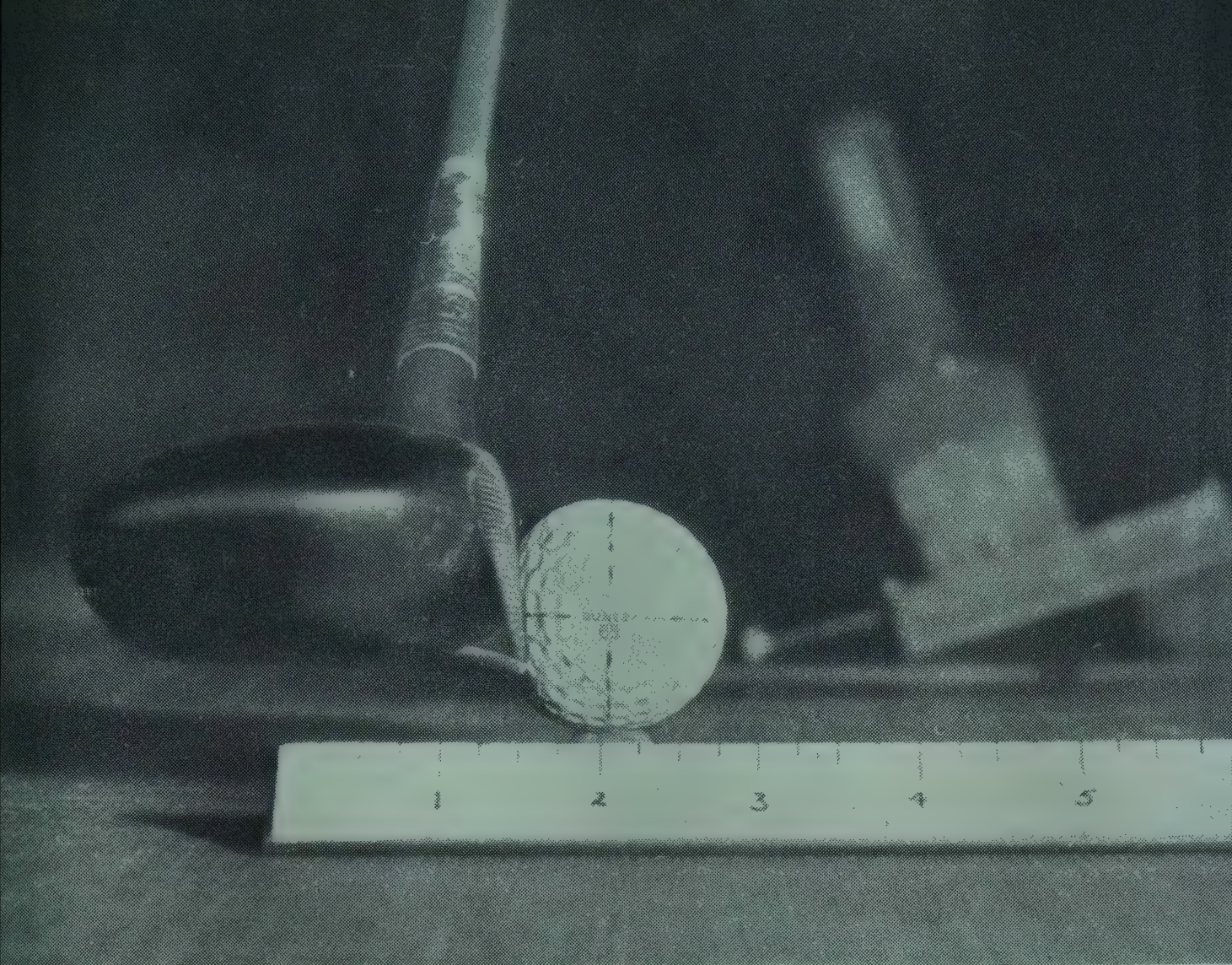


PLATE XI (a)

(Above) A record of the impact of a golf club on a ball, taken by means of a high-speed gas-discharge lamp. The flash is triggered by means of a photo-electric cell. A beam of light crossing the path of the shaft of the club falls on the cell and is cut by the shaft thus actuating the flash.

Courtesy: Kodak Ltd.

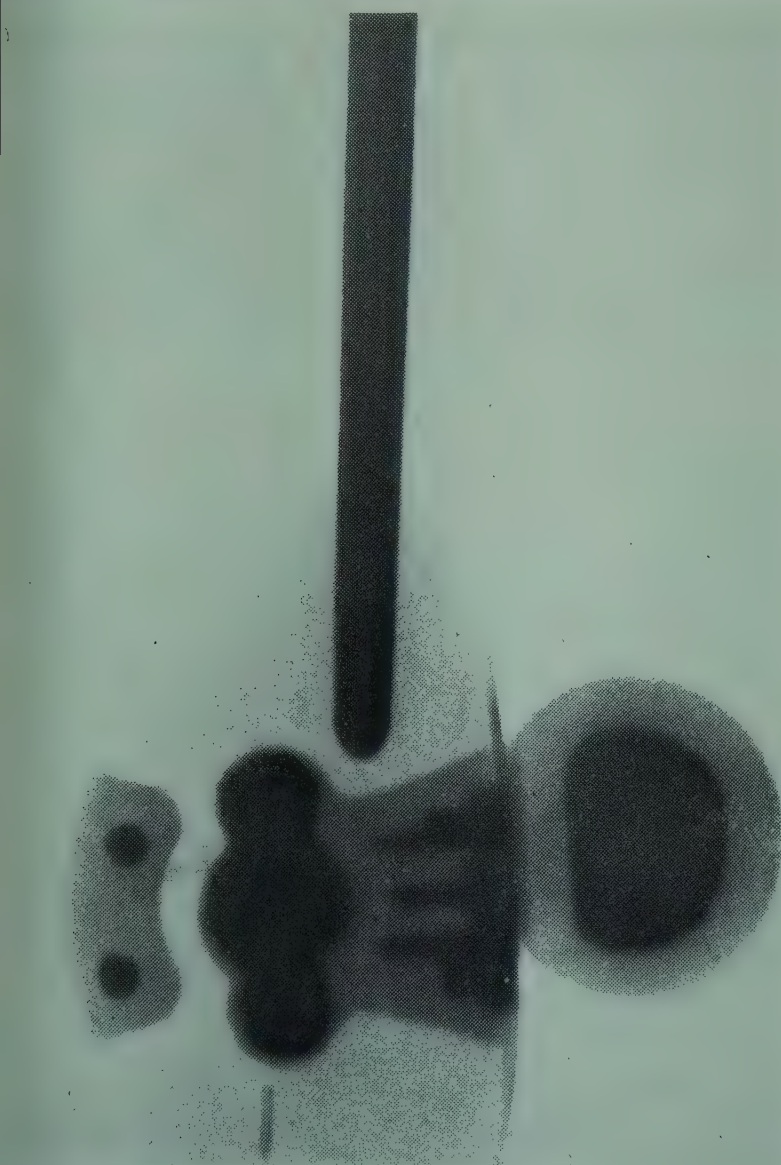


PLATE XI (b)

(Left) A flash radiograph of a similar subject, showing the metal parts in the head of the club and the deformation of the core of the ball.

Courtesy: Westinghouse Electric International Co.

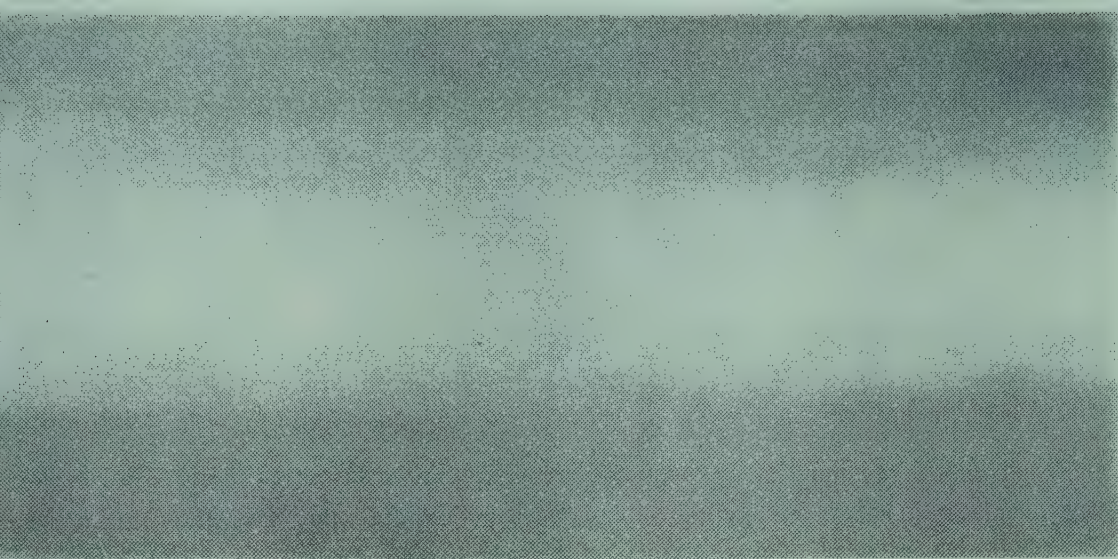


PLATE XII (a)

Courtesy: Kodak Ltd

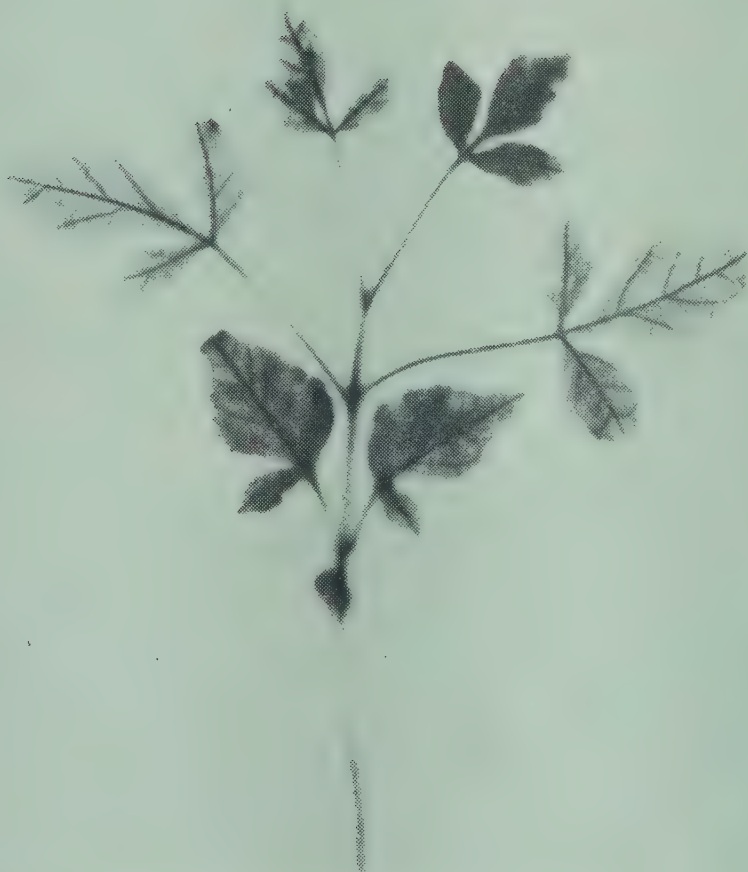
Comparative radiographs of boiler welds. (Above) A satisfactory weld and (right) a highly defective weld in which the metal has failed to penetrate the gap in the plates, merely covering over the surface.



PLATE XII (b)

The use of radioactive tracer elements is shown by this record of a plant fed on a solution of phosphates containing radioactive phosphorus. The record was made by placing the specimen in contact with a suitable plate in the dark, the radioactivity resulting in the fogging shown. The image is darkest where the phosphorus has concentrated most.

Courtesy: R. H. Hertz and Kodak Research Laboratories



RADIOGRAPHY

coat X-ray film on both surfaces and sandwich it between two such screens. The film is thus exposed not only to the X-rays but to the blue light emitted by the screens, to which it is also sensitive. This method tends to produce records having detail which is not clearly defined, due to the light emitted by the screens being diffused. There are, however, many applications in which this presents no disadvantage.

Radiography is now one of the most important applications of photography, with possibly the largest and most diverse individual use. The ability to "see into" or "see through" visually opaque objects is of considerable value in industry and commerce, as well as in medicine, and because of this characteristic, radiography is now one of the main consumers of photographic film, with steadily increasing requirements. One of the reasons why the bulk demand is heavy is that, as radiographs cannot be smaller than the object examined, the image area must often be fairly large in size.

X-rays cannot be focussed by means of lenses or mirrors, and are used merely to cast shadow images of objects. X-rays of a particular wave-length are absorbed more strongly by some materials than by others. Therefore the shadows cast do not necessarily correspond to the outlines of the objects as seen by the eye, but rather to the materials which those objects contain and which absorb X-rays to a varying degree. Thus, flesh and skin, which are relatively transparent to the X-rays used for medical radiography, can often hardly be seen on a radiograph, but bone, which absorbs the rays more strongly, is clearly visible. In practice, the part to be radiographed is placed as closely as possible to the film, with the X-ray tube some distance away. As the radiograph image cannot be smaller than the object under examination, the film used

must be at least as large as the area to be examined. Apart from the heavy consumption of film which this entails, storage problems are greater than with the smaller negatives used in ordinary photography. It is for this reason that the technique of copying radiographs on to microfilm, mentioned in an earlier chapter, is likely to be more generally practised.

It may not be obvious at first sight that a radiograph is a negative. The shadow areas of the image, corresponding to those parts of the subject which absorb X-rays most strongly, affect the film least and thus appear as the most transparent areas of the negative. This is of little consequence in practice, for the picture recorded is so unlike any seen by the average eye that tuition and practice in interpretation is in any case essential, after which it is as easy to "read" either a negative or a positive radiograph. For this reason, radiographic negatives are practically never printed but are studied in the original negative image. This method has two advantages: in reducing the cost of film and avoiding any loss of detail during the printing process.

Although the theory of radiography is simple in the extreme, in practice it becomes a highly skilled technique. Because a shadow image is obtained, the correct orientation of the subject relative to the beam of X-rays is of considerable importance. The "quality" of the X-ray beam (i.e. the wave-length band it covers) is also of considerable consequence, because of the difference in the penetrating power of the rays, and the variation in density of the specimen to be examined. These factors are variables which are somewhat more subtle than might at first be expected. With the first it is not merely a matter of presenting the subject to the X-ray beam in such a way that the plane of main interest is perpendicular

to the axis of the beam—variation in thickness of the parts of interest must also be borne in mind, for the object of the examination may be to ascertain the depth of a fine crack in either a bone or a metal casting. If the beam passes at right-angles to the plane of the crack it is unlikely to be detected, for the difference in density of the subject caused by the thickness of the crack will be minute. The correct orientation required is for the plane of the crack to be parallel, as far as possible, with that of the X-ray beam. If, as is often the case, the crack is irregular and wanders through the substance, this technique will at least show up parts of it, and a number of radiographs taken at slightly different angles will usually disclose the main area covered by the crack. This example shows that accuracy of detection depends upon the effective density of the part affected relative to the density of the whole. Thus X-rays enable two separate sections of the same material to be distinguished provided that they differ in thickness by a certain minimum amount. Similarly, a very thin layer of highly dense material, such as lead, can be detected though embedded in a large mass of less dense material, such as flesh or wood.

To differentiate between the varying thicknesses of different materials one depends upon the nature of the X-rays selected. Soft X-rays (Grenz rays) have relatively low penetrative power and are thus absorbed by materials almost completely transparent to the harder or gamma rays. Although flower tissues can barely be recorded by normal medical X-rays, even when used with very short exposures, the internal structure of flowers can be studied by the use of Grenz rays, resulting in many beautiful radiographs. Sensitivity is increased by selection of the appropriate wave-length. Thus a small piece of wood will be almost opaque to the softer rays and will show up

strongly, while it would appear almost transparent to X-rays of a shorter wave-length. To quote a few examples, Grenz rays have also been used to examine: the structure of small animals and insects; "loading" and water-marks in paper, including bank notes, stamps and cheques; small plastic articles; paintings and wood, especially where the latter is attacked by wood-worm and other pests. There are probably many other techniques which actually employ Grenz rays but which have been merely recorded under the heading of "radiography".

At the other end of the wave-length scale are the gamma rays, which have high powers of penetration and are used mainly for the examination of large metal structures. Radium was originally the source of deep penetration rays, but radiation of this nature can now be produced by means of X-ray tubes. The gamma rays produced by radium correspond to radiation from an X-ray tube operating at about 1,500,000 volts. In view of the scarcity of radium, X-ray sets of extremely high voltage will probably be employed to an increasing extent. Radium is still a useful source of gamma rays, because, although it has to be handled with care, it requires no electrical supply, it is light in weight and small in bulk and spreads rays in all directions, thus enabling a number of exposures to be made simultaneously if desired. As radium itself is extremely expensive, it is now common practice to use other radioactive materials which are more plentiful, such as radon and radioactive isotopes produced by artificial means from atomic piles, although most of these have a shorter active life and are less powerful sources of gamma rays. A radon source when new has a higher gamma-ray emission than a radium source of the same size but retains its useful life for only a few days, whereas radium would be equally active after a lapse of hundreds of years.

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Between the two extremes of Grenz rays and gamma rays are the rays with medium powers of penetration, which are normally used for medical and industrial work. The degree of penetrative power, which depends upon the wave-length used, is adapted to particular circumstances by the use of a tube working at the appropriate voltage. The low density of body tissues necessitates the use of fairly soft rays, while industrial work generally requires the use of harder rays.

The applications of medical radiography are too numerous and specialized to discuss in detail. Radiography is invaluable when used in surgical work and enables internal bodily conditions to be examined without resort to actual surgical operations, which, if necessary, can later be restricted to the region required. Radiographs enable broken bones to be examined carefully before being set, again after setting to confirm their positions, and later to observe their satisfactory knitting together. Radiography is also used in dentistry and in the specialized treatment of fractures and diseases of the bones, to determine, for example, the exact position of any metallic plates, wires or pins needed to strengthen points of fracture or weakness. Often the insertion of this type of metal fastening is observed, stage by stage, by radiography. A special technique has been perfected which enables X-ray films to be processed in little over a minute, so that the surgeon can observe progress and examine them as he proceeds with the operation.

Medical radiography is not restricted to examination of the skeleton. It is used to examine soft internal organs, veins and arteries. Some of these structures can be seen without the use of special aids, if rays of the correct wave-length are used, but other structures have to be made to reveal themselves by introducing into them substances

which are opaque to the radiation. This can be done by giving the patient a meal containing a barium salt, thus enabling the digestive organs to be radiographed as dense areas. The progress of the meal through the digestive system can thus be followed in a series of radiographs. Similarly, the heart and blood vessels can be examined by radiography after an injection of an opaque medium into a vein.

The lungs can be seen quite clearly without the need for any special treatment. This factor has proved extremely important in the detection of pulmonary tuberculosis and has been the means of saving many lives, as the disease can be treated with a high degree of success, if detected in its early stages. For this reason doctors have recommended that the whole population should be examined regularly by radiography. This would not only simplify subsequent treatment but would also reduce the spreading of the disease by infected persons. An examination on such a scale is an immense task, but a start has been made by arranging for the periodic examination of certain selected sections of the population, especially in areas most prone to the disease. This has been facilitated by the introduction of "mass miniature radiography". This technique enables radiographs to be made on much smaller sizes of film than normally used, in spite of the fact that no type of lens or other focussing arrangement can be used with X-rays.

As mentioned earlier in this chapter, X-ray images are shadows and are therefore recorded upon film of the same size as the object examined. Although the X-rays themselves cannot be focussed to provide a smaller image, there is no difficulty in photographing the shadow on a reduced scale, if it can be made sufficiently visible. If, therefore, the X-ray shadow is cast on a fluorescent screen, the visible image produced can be recorded by means of

an ordinary camera. In practice, such a scheme relies upon the production of an image on the screen of sufficient brightness to enable a short exposure to be made. This has been accomplished with the aid of modern wide-aperture lenses and fast films designed for the work.

Mass miniature radiography is carried out by means of an apparatus consisting of a screen, against which the patient stands, and an automatic camera which takes a small film record of the screen. The camera contains a roll of film capable of recording a large number of miniature radiographs, and is connected to the X-ray outfit and screen in such a way that double exposures are avoided and each picture is numbered for identification purposes. Patients therefore can be dealt with at the rate of up to 350 an hour and the resulting miniature films are quickly scanned for indications of lung disease. No claim is made that these films enable a certain early diagnosis to be made but experience has shown that they provide a useful guide in the majority of cases, enabling doubtful conditions to be selected for a further examination by means of full-size radiographs. Thus, large numbers of infected persons are discovered at a much earlier stage than they otherwise would have been, leading to a reduction in the spread of the disease and better chances of recovery for infected patients. As the equipment can be carried in a van, it is unnecessary for those requiring examination to travel to a clinic. The mobile units are taken to factories and used by local authorities to sift large numbers of people quickly, with a minimum of interruption to their daily work. A London borough was recently reported to have made arrangements to examine every person within its area by this means.

Although medical and dental radiography has been in use for many years, the last decade has seen a very great

increase in the use of industrial radiography. X-rays are of particular value in the examination of manufactured articles because they provide a means of testing without destroying the part concerned. Furthermore, every article made can be examined, if necessary.

In the past there was no means of determining whether a casting or a weld was perfect except by cutting it apart, often in several different places. Similarly an assembled article, such as a fountain pen, an electric immersion heater or a fire extinguisher, had to be taken apart to examine the efficiency of assembly. In these cases, only a limited number of every thousand articles manufactured could be selected for examination, or production would quickly become uneconomic. Radiography enables a suitable individual examination to be made, in most cases without harming the article. Films can be kept as records of the testing of particular items and may also be used to determine the reasons for faulty manufacture. In some cases it is economic to examine total output, while in others only a certain percentage of parts is sampled.

Radiography is widely used in examining light alloy and steel castings because it enables defective parts to be scrapped before any machining is carried out and thus saves time and money at an early stage of production. Radiographs will detect and show such defects as shrinkage, tears, cracks, gas cavities and other faults, provided these occupy at least 1 per cent. of the thickness of the metal in the direction of orientation of the X-ray beam. Similar defects can be shown in welds, a factor of considerable value in deciding their strength. It is becoming common practice to radiograph all important welds, and Lloyd's insist, for example, upon radiographic proof of the quality of welds in all high-pressure marine boilers before an A.I certificate is issued.

RADIOGRAPHY

A vast number of specific industrial applications of radiography have been recorded. These range from the examination of the spacing of the coils of wire in an electric heating element embedded in refractory cement, to that of foodstuffs, such as chocolates or tinned fruit, for internal metallic impurities. Soft X-rays have been used to examine carbon arc electrodes for imperfect cores, and cloth for variations in weave or of dressings applied to it. Other materials examined include plastics, refractories, glass, china, leather, paper, wood, stone and coal.

The increased use of radiography in the examination of manufactured products has led to interesting developments in mechanized methods, though these are still in their infancy. The simplest of these is a system whereby castings or other objects are placed in trays on the film-holder and a rapid exposure is made with an overhead tube, thus enabling large numbers of components to be handled quickly. An extension of this method carries the trays of parts on a conveyor belt under the tube, halting each tray for an instant while the exposure is made. This enables about 10,000 small castings a day to be examined for flaws. A complementary approach to the problem, in cases where larger assemblies are involved, is the use of a small mobile set which can be placed in the position required for each record and is towed by car from one assembly to another. With either method, the number of X-ray films exposed is so great that normal methods of handling created a bottle-neck. Machines capable of developing, fixing and drying the films automatically have, therefore, been made and these enable over 500 films per hour, 14 × 17 inches in size, to be handled.

Where it is desired to locate the depth of a defect, it is possible to produce stereoscopic radiographs which enable the depth of an object to be viewed, as if made of

transparent glass or plastic. This process is, however, unnecessarily elaborate and the defects can easily be located from a single film by means of a double exposure. The technique is to move the X-ray tube through a known distance between two exposures. As X-rays travel in straight lines from the tube to the film, this will result in a double image. Those parts of the object in contact with the film will be recorded in the same position by both exposures, but any defect in the thickness of the object will be recorded as two images separated to an extent dependent upon its distance from the film. A simple geometrical calculation will enable the height of the defect above the film to be determined if the film-tube distance and the distance of tube shift are known.

A further important modern advance is the technique of flash radiography, which enables sharp records of moving objects to be obtained with very short flashes of X-rays. The technique of high-speed flash photography has been discussed in Chapter 4. A very short brilliant flash of light can be produced by discharging a condenser through a gas tube. Similarly, a short flash of X-rays can be produced by a sudden discharge through a specially designed X-ray tube. Flashes of X-rays as short as one millionth of a second have been produced, thus enabling the insides of opaque swiftly moving objects to be examined. The passage of dust through a vacuum cleaner and the behaviour of the core of a golf ball at the moment of impact with the club were among the first examples shown. During the last war, many armaments problems were tackled by this method, including the behaviour of a projectile inside the barrel of a gun, the burning of rocket motors and the phenomena inside explosive charges at the time of detonation.

For some years, research has been carried out on the

technique of cine-radiography and it has proved possible to make moving pictures of the action of human joints and other muscular movements. Two methods are used. One is to employ a cine-camera to photograph a fluorescent screen, as in mass miniature radiography, and the other is to take a series of full-size radiographs in rapid succession which can be subsequently copied in sequence and in correct register on to a length of normal cine film. Either method involves considerable difficulties but can be made to give good results with subjects which are relatively easy to penetrate. The smaller parts of the body, such as the hands, arms, feet and neck, are fairly easy to record in this manner and fascinating films are available to show the working of finger, wrist and knee joints, and the action of swallowing.

Recording of the thicker parts of the anatomy is more difficult and leads to some risk of giving the patient a dangerous over-dose of radiation. However, films of such things as shoulder movements, the pelvis, or the action of the heart are available. Picture frequency is limited, so that normal speeds or slight degrees of slow motion only are possible. In the industrial field the technique is limited by the exposure required but good records have been made of small subjects which are not radiographically dense, such as the pouring of metal into small moulds and the behaviour of an arc welding electrode inside its coating.

Although X-rays, unlike light, cannot be focussed and therefore do not permit any form of magnification of the image, a technique known as "X-ray micrography" or "microradiography" is available. This consists of the production of high-resolution radiographs on fine-grained photographic plates, the negative subsequently being greatly enlarged by normal optical methods. The high

resolution in the negative is achieved by the use of an X-ray tube with a small focal spot, placed some distance from the specimen, which must be thin and placed in close contact with the surface of the plate. The material used to record the image is of a type designed for very high resolution; it is possible with certain plates to record as many as 25,000 lines to the inch, permitting degrees of enlargement comparable with those encountered in low-power photomicrography. The enlargement is, in fact, usually carried out by making a photomicrograph of the negative. In this way the internal structures of minute bones, metal specimens, spot welds, fibres and other small objects have been examined.

We have so far been concerned with the use of X-rays in the penetration of visually opaque materials to enable their interior structure to be examined. X-rays are, however, used for other purposes, the most important being X-ray diffraction. This technique enables the crystalline structure of a material to be examined. As with radiations of longer wave-length, X-rays can be diffracted. Whereas a diffraction grating (a slab of glass or metal ruled with 50,000 or more parallel lines per inch) can be used to divert a beam of light and split it into its component wave-lengths, X-rays have a very much smaller order of wave-length and need a correspondingly finer grating. It is not possible to rule a sufficiently fine grating, but the spacings of the planes of atoms in crystalline bodies is of the requisite order of magnitude. If a beam of X-rays is allowed to fall upon any crystalline substance it is scattered in a regular pattern. The scattered beams can be recorded on a photographic film as an "X-ray diffraction pattern" which will be typical of the arrangement of atoms in the crystal and of the X-ray wave-length used. Most substances are in fact crystalline, although they are not commonly thought of as

containing crystals. Even those substances which are not strictly crystalline often exhibit some crystalline features under certain conditions and these can be shown by means of X-ray diffraction. Only purely amorphous substances exhibit no trace of a diffraction pattern.

X-ray diffraction patterns have a large variety of uses. They are employed by the experimental physicist and chemist to elucidate the crystalline structure of metals, organic compounds, fibres and hair. They are used by the metallurgist to determine the state of a metal under particular circumstances and by the industrial chemist to identify substances and to analyse mixtures of substances. The X-ray diffraction patterns of materials can, in fact, be used in much the same manner as their spectrograms, except that the X-ray patterns give much more indication of structure and less of the proportions of the substances present. As an example, spectrography in a metal alloy will give the relative proportions of the metals present while X-ray diffraction patterns will show the crystalline structure of the alloy, which is often affected by its composition. It also enables compounds to be distinguished by their structure; spectrography will allow the elements present to be determined but X-ray diffraction can often differentiate clearly between different compounds of the same elements. Further than this, it enables the state of a metal to be decided, for the effects of cold working, annealing and fatigue are apparent in the crystalline structure of the metal. Examination of the crystal structure is again of assistance to the chemist in deciding the constitution of the molecule, an essential first step in the synthesis of organic compounds. The crystal patterns of human hair have helped to give some clue to the nature of the very long chain molecules it contains and have thus assisted in improving our knowledge of the mechanism of

artificially waving hair, resulting in the adoption of improved methods of permanent waving.

An interesting application of X-ray diffraction is in the elimination of boiler scaling. There are a number of different types of scale and sludge encountered when hard or partially softened water is used in boilers. These substances are not easy to identify by normal chemical and crystallographic means but X-ray diffraction enables them to be distinguished without difficulty—not only their chemical identities but also their crystalline species, a knowledge of which is of great importance in the prevention of scale. Other similar cases of the use of this method for identifying substances include the identification of rust in cutting lubricant, showing the undesirable presence of water, and of the various substances formed during complex reactions, such as in the manufacture of bleaching powder from slaked lime and chlorine. Natural pearls can be distinguished from cultured and real gems from synthetic. The best orientation of jewels for cutting for use in watch and instrument bearings can also be determined.

X-ray diffraction is thus being widely used for the identification of chemical compounds and alloy components, to distinguish between compounds and solid solutions, to determine structural changes in metals during annealing, rolling, drawing, shaping, stamping, cupping, etc., especially with a view to anticipating the effects of such changes upon the final manufactured article, to study corrosion, plating, enamelling and surface films of various sorts, for the study of the composition and purity of many complex organic compounds and in a large number of other ways.

Such work would be very difficult without the assistance of photographic materials, for the positions of spots in diffraction patterns must be accurately measured, and this would be almost impossible without a permanent visible record.

Chapter 9

ATOMIC PARTICLES

OF THE many types of radiation which affect photographic emulsions the radiation of atomic particles is of special interest. In themselves they have at present no very definite applications, yet the fact that they can form a latent image on a photographic plate is of considerable importance. The use of the photographic plate as a means of detecting and identifying atomic particles is of essential importance in atomic physics, from which arises the use of "tracer elements" for other purposes and where the use of the photographic plate is again sought. Mention at this stage should also be made of the electron microscope, for without the sensitivity of photographic material to electrons the value of this instrument would be limited.

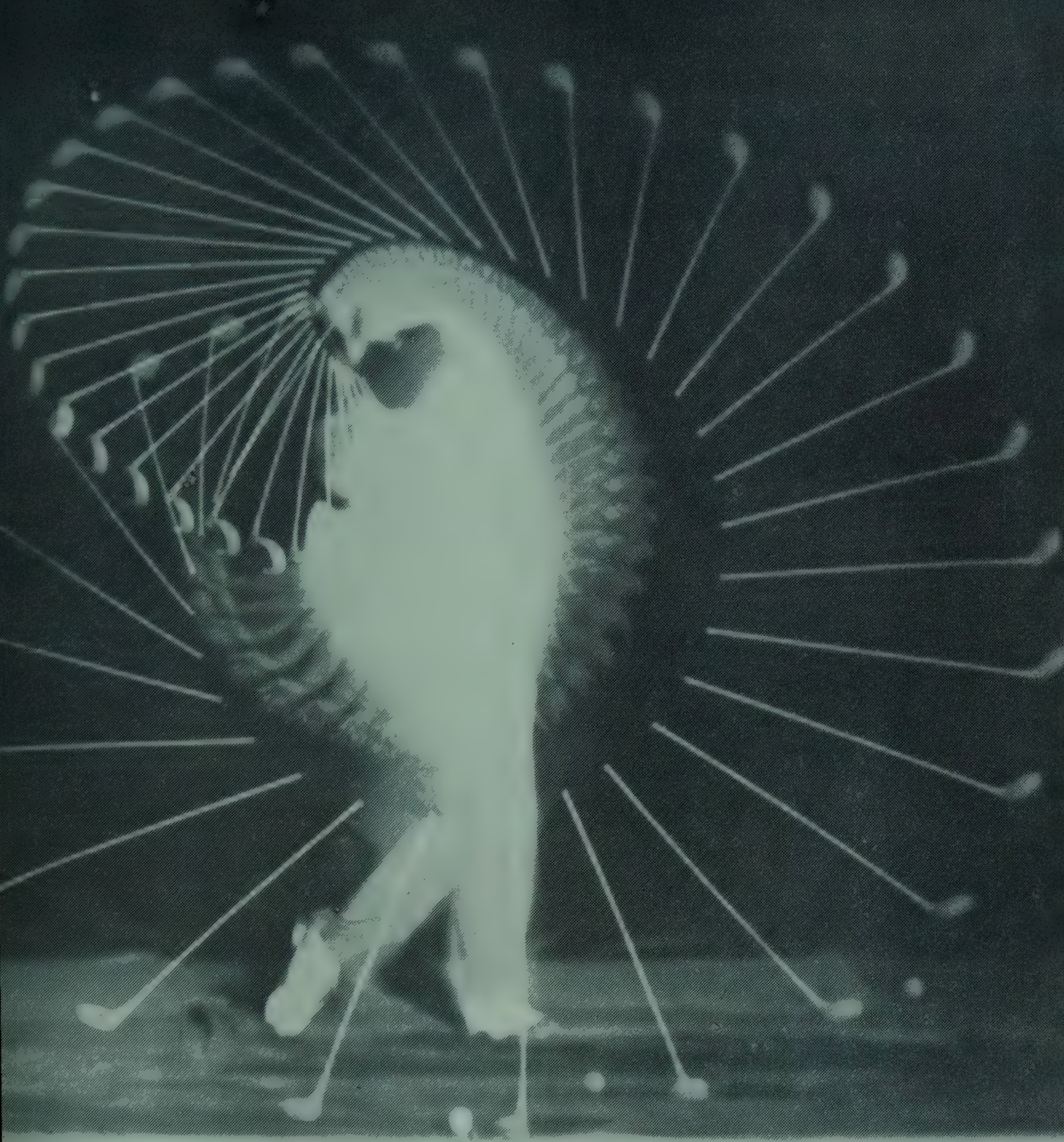
In the accepted theory of the composition of chemical elements each comprises atoms consisting of a nucleus round which electrons rotate in orbit, much as the planets move round the sun. The composition of the nucleus and the number of planetary electrons varies from element to element, each having its own characteristic arrangement. The nucleus is very small compared with the total size of the electron orbits but contains most of the weight of the atom. As a result of atomic collisions or radioactivity, electrons and other charged particles can be ejected by the nucleus. Other constituent parts of the nucleus are the protons, which are positively charged, neutrons, which are similar in mass but uncharged, and

alpha particles, which have four times the mass and twice the charge of protons.

Charged particles were at first detected by a Wilson Cloud Chamber or a Geiger counter. The former has already been mentioned in Chapter 3 as an example of a scientific indicator instrument with which photography could be used to record observations. It consists of a small chamber in the form of a cylinder with a glass top and a movable piston below. The chamber contains a gas and water vapour. If the volume of the chamber is suddenly increased by lowering the piston, the water vapour tends to condense. Rapid condensation will take place only, however, if dust or other particles are present to form a core for the water droplets. Thus for a brief period after lowering the piston, no cloud forms. If during this period an alpha particle is fired into the chamber, the gas in the path of the particle is ionized and the water vapour starts to condense on the ions, when the path of the particle becomes visible as a fine thread of water droplets. A moment later the whole chamber fills with cloud and all is lost to sight. In the meantime, however, a flash photograph of the track can be made for subsequent leisured study. This will not only show its track but also what happens if the alpha particle happens to hit a molecule of gas in the chamber. Should this take place, the particle bounces off at an angle which can be measured, and the impact may produce other particles from the atoms in the molecule of gas.

The use of photography in this technique can, however, be of more direct value, for emulsions have recently been made which are capable of recording the passage of all charged particles of any energy.

It is a recognized fact that any photographic emulsion is sensitive to certain charged particles and to atoms them-



LATE XIII

Courtesy: H. E. Edgerton

Multiple-flash record of Densmore Shute's swing. The interval between flashes is $1/100$ th second at all points. Thus the velocity of the club at various stages in the swing can easily be calculated. Note the higher velocity of the ball.

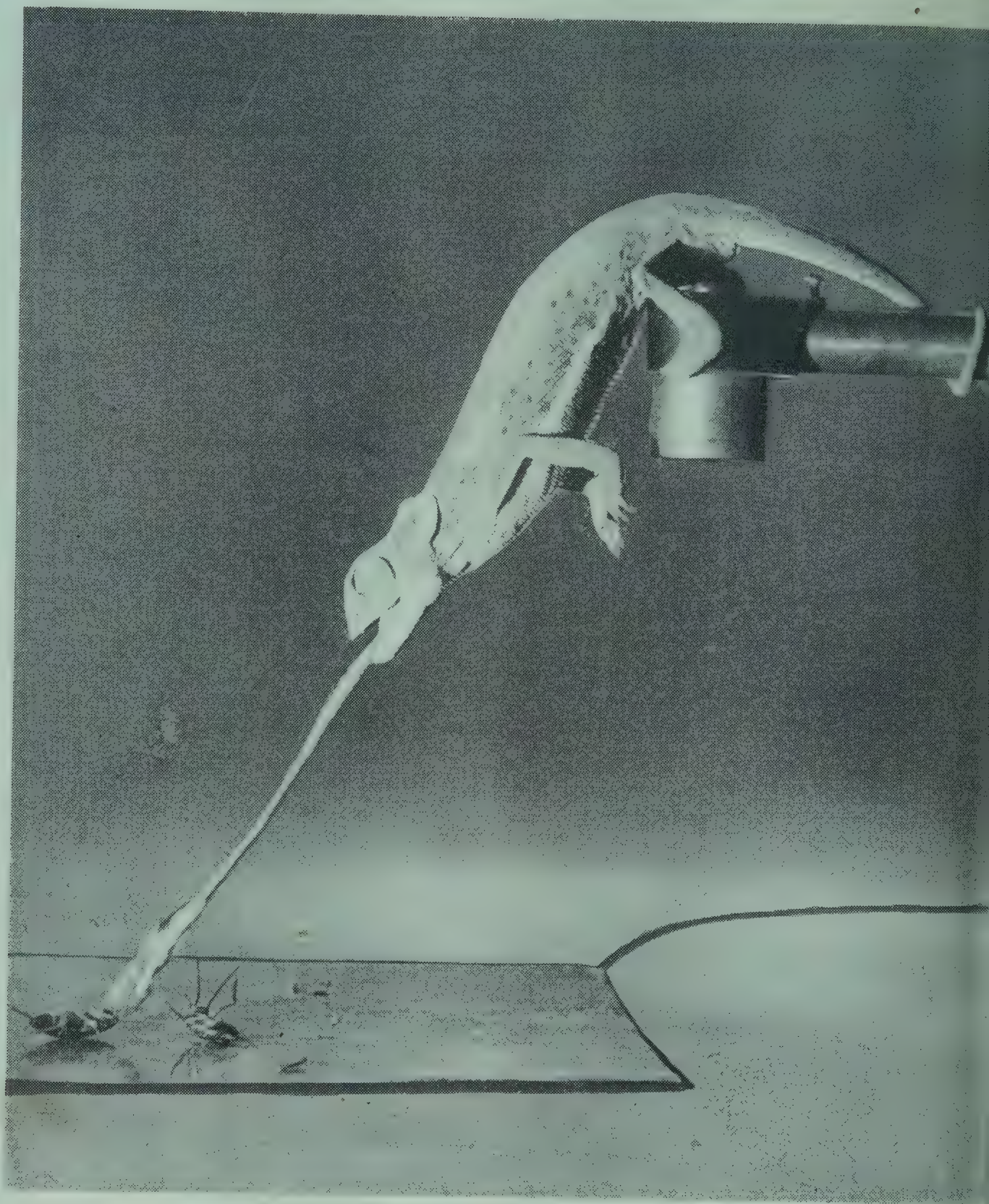


PLATE XIV

Courtesy: Kodak Ltd. and The Zoological Society of London

A chameleon at lunch. The tongue action of such reptiles has been studied by high-speed photography, as it is too swift to be observed by eye.

selves, if struck by these particles at high velocities. The Mass Spectrograph made use of this property some years before the 1939-45 war. This instrument is used for classifying atoms accurately in terms of their respective weights. A stream of atoms is ejected in a straight line from a small aperture inside an evacuated tube. These atoms are electrically charged or ionized and therefore subject to deflection by electric and magnetic fields. The amount of this deflection can be made to depend solely upon the ratio of charge to mass of the atoms. Atoms of the same charge but with a different weight can therefore be sorted and, if allowed to fall upon a photographic plate, will record their "mass spectrum". Atoms of an element which all have the same charge but differ in weight are called "isotopes". The isotopes of an element are all identical in chemical behaviour and can only be grouped by the Mass Spectrograph, which relies entirely upon photography to record its results.

The most important aspect of the recording of these particles is, however, the information which their "traces" provide about the particles themselves. In passing through the emulsion layer, particles "expose" the grains along their path, thus making them capable of being converted to silver by a developer. Emulsions used for normal photography do not indicate these tracks very clearly, as the emulsion grains are set rather far apart, but special emulsions have been prepared which now enable the particles to be studied without difficulty. As the particle travels through the emulsion layer, it loses energy by ionizing the silver halide grains it meets in its path. The number of ionizations it can make depends upon its charge and speed. Hence its effects upon the silver halide grains (which form the track produced by its passage) shows the nature of the particle.

A heavy particle such as an alpha-particle produces so many ionizations that a complete train of silver particles is left along its track in the emulsion after the plate is developed. A proton has a higher velocity and leaves some gaps along its path where the silver halide grains have not been affected, but as it slows down, the gaps are reduced, until the end of its track resembles that of an alpha-particle. A neutron, having no charge, leaves no track, but may show its presence by collisions with the nuclei of hydrogen atoms present in the emulsion, and which release sufficient energy to affect a few silver halide grains. Electrons, being small in mass, are scattered easily, and leave haphazard winding tracks in the emulsion.

All these tracks are minute and have to be studied under a microscope. By this means, the parent particles can be identified and much information about them obtained. The "traces" can be seen under the low powers of the microscope but can only be examined properly by means of an oil-immersion lens. This makes the task of analysing them slow, but nevertheless provides a valuable source of knowledge of the characteristics of the particles. Measurement of the length of a track can provide information about its energy, while the mass of a particle may be indicated by the number of grains affected in a unit length of the track. Nuclear disintegrations and transmutations of one element into another can be studied by impregnating the emulsion with an element under examination and allowing a stream of charged particles to fall upon it. The emulsion subsequently has to be searched for "stars" consisting of a number of tracks of different lengths radiating from a point. This point shows the position of the disintegrated atom, the tracks being caused by the particles released by the disintegration. Such stars can be produced by the action of cosmic

radiation. This is relatively weak at sea level but increases in intensity at higher altitudes, the character of the particles concerned changing as the atmosphere becomes thinner. Photographic plates are sent up attached to balloons, to study particles at extreme altitudes. When a predetermined height is reached, the plate is automatically released from the balloon and returns to earth by parachute. It is doubtful whether the information so provided about cosmic rays could be obtained by other means.

Research in the production of special plates for this work has led to rapid results. Originally, plates thickly coated with emulsions containing densely packed small grains were produced, which recorded excellent tracks of the slower, highly charged particles. These plates were, however, of low sensitivity and research continued for some years before electrons could be recorded. Since 1948 it has been possible to record the tracks of charged particles of any velocity, and this factor has proved invaluable to the nuclear and cosmic ray physicist.

Another technique which is of great and increasing importance is that of autoradiography. This involves the use of photography for recording the distribution of radioactive substances in minerals, metals and plant or animal tissues. In recent years, developments in nuclear physics have made it possible to obtain radioactive substances fairly easily and they are now commonly used as "tracers". This means that in order to follow the passage of a particular element through a physical process, a sample of it is rendered mildly radioactive so that it can easily be identified from its surroundings.

Extensive use is now being made of this method of studying the passage of chemical elements through plants, animals and human beings. Thus by feeding a plant with a solution containing a minute quantity of one radioactive

element, the rate at which this is absorbed, its path through the tissues and its final destination can be determined. The distribution of the radioactive material in the structure of the plant can be followed by placing appropriate portions of it in close contact with a photographic material for some hours. The nuclear particles released by the radioactive element affect the photographic material and the pattern of the element in the tissues of the plant is revealed upon development of the plate. This method may be used either to cover the total structure, or to examine small portions of the organism. Special photographic materials are available which have such a high resolving power that it is possible to study the detailed distribution of the tracer element even in the walls or contents of the cells of plants and animals. The amount of radioactive material required for this purpose is so minute that the living organism which absorbs it is not harmed, nor is the investigator who uses it in any danger. Yet the photographic material records it faithfully.

In order that sufficient detail may be recorded, contact must be well established between the specimen to be studied and the photographic emulsion. One method of achieving this state is to prepare a section of the specimen, float a specially prepared emulsion layer on the surface of a dish of water and allow this to fall upon a microscope slide holding the section of the specimen. After the whole sandwich is dried, it is left in the dark to allow the radioactive material to affect the emulsion. This may take several days or weeks, depending upon the activity of the tracer element. After processing, the sandwich is viewed as a whole under the microscope, the image in the photographic layer appearing superimposed upon the actual section, in order to locate exactly those areas occupied by the tracer.

This technique is as yet in its infancy but is already in widespread use for the study of plant and animal metabolism, in pathology and in metallurgy. The application of the technique to metallurgy may seem surprising but the method has been used to trace the path of minute quantities of metallic impurities, lubricants and bearing metals, and again has proved very useful. It seems probable that improvements will enable even a few isolated radioactive atoms to be detected in biological or chemical specimens by the tracks of the individual particles they emit. This would lead to an even greater increase of accuracy in the location of tracer elements contained in still more minute quantities of material.

The sensitivity of photographic emulsions to electrons has proved of considerable value in hastening the development both of the electron microscope and of electron diffraction techniques. As mentioned in Chapter 7, the maximum resolving power obtainable from a microscope depends upon the radiation with which it is used. Resolution is increased in the ordinary optical microscope by using shorter wave-lengths of light, and ultra-violet radiation enables the finest detail to be observed. The resolving power of the electron microscope is much greater still, as the effective wave-length of an electron beam is very much shorter than that of any radiation in the visible or ultra-violet regions. The effective wave-length for electrons generated at around 50,000 volts is about $1/100,000$ th of that of blue light. Thus the useful limit of magnification in an electron microscope is about 100,000, compared with a figure of about 2,000 available with the use of the best optical microscopes.

The electron microscope utilizes magnetic or electronic "lenses" to control the electron beam, the specimen to be examined being held on a thin membrane at a suitable

point in the optical system. In order to provide an unobstructed path for the electrons, the whole of the interior of the microscope has to be evacuated and the specimen must therefore be suitable for use in a vacuum. It is introduced into the microscope on the membrane (which is supported on a fine metal grid) through an air-lock, which avoids the necessity for pumping out the whole microscope each time the specimen is changed. A similar air-lock is used for the insertion of the photographic plate. The grid used to support the specimen on its membrane is produced by photographic means, as this provides the easiest method of manufacturing small pieces of fine-mesh grid (*see page 150*).

The image of the specimen formed by the electron beam can be examined visually by means of a luminescent screen viewed through windows in the walls of the microscope. This enables the portion of the specimen and the optimum degree of magnification to be selected, though the screen does not easily permit examination of the fine detail of the specimen. When adjustments are completed the image is recorded on the photographic plate, the exposure required normally being a matter of seconds. It is customary to photograph several negatives on a single plate, which can be moved to expose different portions of its surface to the image area. All movements of the photographic plate and the specimen to be recorded are mechanically controlled from the exterior of the microscope to avoid breaking the vacuum.

The technique of electron micrography has introduced several novelties of procedure. The magnification is so great that the smallest specimen holder which can conveniently be used appears as a large expanse and has to be "scanned" carefully to ensure that no details are missed. Specimens must be capable of withstanding the

effects of the vacuum; they cannot therefore be wet or susceptible to damage by dehydration or loss of other volatile components. They must not be too thick, and so cause excessive heat to be produced following the impact of the electron beam. This is a complication with which the user of an optical microscope does not have to contend, but which can be most troublesome in an electron microscope. Under some circumstances, inorganic materials melt or vaporize if exposures are at all prolonged, while various changes can occur in organic specimens.

The photographic problems, too, are extensive. The plate must be able to withstand the vacuum without becoming physically damaged and prolonged pumping times must be avoided. Some of the early plates which were used blistered and cracked, or the emulsion stripped off the glass. Some required prolonged pumping to remove all the water held in the emulsion, which caused, if left untouched, a slow decline in the vacuum. Films have proved less suitable than plates because the solvents liberated cause prolonged pumping times and a tendency for the film-base to become brittle. The response of emulsions to the electron beam is different from their reaction to light or X-rays. The variation in speed is much more restricted and contrast is not related to speed in the same way as with the use of light.

The images produced are often quite unrecognizable to the eye, partly as a result of the enormous magnification, and also because the relative transparency of parts of the specimen to electrons depends upon various properties besides thickness. The latter problem is much the same as the examination of a radiograph of a limb when compared with normal visual appearance.

In order to obtain more information on the thickness

and contours of the specimen, it is often "shadowed" with a minute "spray" of metal (this spray is in the form of a beam of metal atoms). The shadowing is carried out before the specimen is placed inside the microscope for examination. The "spray" is directed upon the specimen at an angle so that a shadow of the outline of the specimen is formed in metal on its surface, in much the same way as wind will produce drifts and "shadows" of walls, trees, etc., in snow. In the resulting electron micrograph the metal, being relatively opaque, provides shadows clearly superimposed on the specimen, the final effect being similar to that shown in a photograph recorded with the assistance of a spotlight, the latter directed obliquely at the specimen, enabling the relative heights of different parts of the specimen to be deduced. Some surprising discoveries have resulted from this technique, one being that the flagellæ of some bacteria, thought to be lying on the specimen-holder, were, in fact, looped high in space above it.

The applications of the electron microscope are so widespread that no attempt can be made to survey them in a few paragraphs. Wherever the optical microscope is used for higher magnifications of specimens the electron microscope can also be used, provided that a suitably thin specimen can be prepared which the electron beam and vacuum will not destroy. The electron microscope has been used in most branches of science and technology and among some of the more spectacular of its applications have been the examination of micro-organisms of many types, viruses, cell-structures in plants and animals, finely divided powders (such as face powder), adhesives and lubricants. The instrument is well adapted to the examination of particles of small size, too fine to be revealed by the optical microscope. The chemical behaviour of a

finely pulverized material is often different from that of the same substance in its normal state. Such materials as carbon black, used in inks and plastics and as a preservative in certain rubbers, and paint pigments, such as titanium oxide, have been examined and their behaviour linked to their particle size and shape. Electron micrography is now being used, in some cases, as a routine check on samples from manufactured stocks.

A further technique which utilizes the sensitivity of photographic film to electrons is that of electron diffraction. This is similar in principle to the X-ray diffraction technique described in Chapter 8 but is applied principally to the study of extremely thin layers. It has enabled information to be gleaned on the polishing of surfaces, lubrication and on surface chemical reactions. The reason for its suitability for such work lies in the nature of the electrons, which can only penetrate short distances into solids. The technique thus provides information about surface structures which is not confused by diffraction patterns from the deeper layers of the material examined. The normal degree of penetration is less than 500 Angstrom Units (i.e. about $1/20,000$ th of a millimetre). This enables, for example, the adsorbed layer of lubricating oil on a metal surface to be examined. The oil molecules have been found to be attached to the metal surface at one end and to stand out from it, rather like the pile of a carpet. There appears to be a connection between the orientation of these molecules and the lubricating properties of the oil. Similarly, the flat plates of graphite which adhere to a lubricated surface have been found to be orientated in a manner which provides the easiest cleavage of the crystal.

It is only in recent years that work has been carried out on the production of plates especially suitable for the

recording of atomic particles. At present, considerable strides have been made, and there is reason to suppose that as applications become more widespread even more efficient materials will be produced. Meanwhile, there is ample room for scientific work to be carried out with the new tools which this branch of photography has provided.

RECORDING AND ANALYSIS OF MOTION

THE VALUE of photography in the analysis of motion has already been referred to in Chapter 4. By means of a short flash of light, fast moving objects can be stopped in flight and their appearance and position clearly recorded for subsequent study and analysis. Photography can, however, improve on this technique. "Still" photographs will reveal yet more information by means of a double exposure recording the shift of the object from one instant to another, or by tracing the track of the object's movement as revealed by a light attached to the object. Further information still can be obtained by cinematography, which not only enables movement to be reproduced but also allows extensive control of the time factor. The apparent movement, projected upon a screen, can thus be slowed down or speeded up to a considerable extent.

Before considering the wide range of applications which this aspect of photography presents, it is as well to review briefly the cinematographic and allied techniques now available. The broad principles of cinematography are generally understood. The camera exposes sixteen or twenty-four small pictures per second along a strip of perforated film. This strip is developed and printed, resulting in a positive film record which can be projected to reproduce on a screen a visual impression of the original movement. If the speed of movement of the image is to be the same as that of the original subject, the print must be projected at the same picture frequency as that at which the negative

was exposed. Although this will normally produce a sufficient illusion of reality, it is important to remember that a "moving picture" on the screen does not, in fact, move at all. If the speed of vision of the eye were greater, we should be able to see that a single "still" picture was being projected on to the screen followed by a rather longer period of complete darkness and then another picture, this being repeated *ad infinitum*. For normal entertainment purposes this is of no consequence but in technical work it may lead to difficulties. In the first place, any phenomenon which occurs while the camera shutter is closed, between a pair of adjacent pictures, is not recorded at all. This period, though short, is long enough to contain a complete action which could be seen by the eye, such as a spark or flash, but missed while the shutter remains closed. Secondly, it may lead to stroboscopic interference with repetitive action by the subject—e.g. the familiar but somewhat perturbing sight of spoked wheels rotating backwards as a vehicle advances. Finally, it prevents slow motion effects from being obtained by merely slowing down the projector, for this at once produces a noticeable flicker and if the frequency is further reduced, discloses the individual "still" pictures.

The rate of projection is thus fixed within limits—it must be fast enough to satisfy the eye, but slow enough to avoid injury to the positive or the use of excessive lengths of film. The camera speed can, however, be varied at will, and if this is increased, a greater number of photographs will be recorded in a given time, thus using more film, which will therefore take longer to project at the standard speed, the showing of the movement thereby being extended over a longer period on the screen. This is usually referred to as "slow motion" (if the movement is slowed down to about one-eighth of normal or

less) or if the movement is slowed down even more than this as "high-speed cinematography".

The opposite effect is produced if the camera speed is reduced—less film has been exposed during recording and will therefore be projected over a shorter period of time, thus appearing to speed up the motion of the image. This is known as "speeded-motion" or "time-lapse" cinematography. Thus the apparent speed of the subject can be altered substantially, and a valuable means of analysing movement becomes available.

There are certain mechanical difficulties involved in the carrying out of alterations in camera speed, though in recent years research has found ways of overcoming practically all of them. The least difficulty is that of slowing down the camera. For much of the work it is quite satisfactory to drive the normal camera mechanism by a geared shaft rotating at low speed, though this has the disadvantage of producing a long exposure time, as well as a low picture frequency, which, if the subject is moving, results in blurred pictures. In such cases, short exposures must be given at relatively long intervals. One method, among others, involves the use of a gas-discharge flashlamp which is triggered off each time the shutter reaches a certain point in its travel. In any case, "time-lapse" photography needs artificial lighting, as daylight varies considerably in quality and intensity. The degree to which the camera can be slowed down is virtually unlimited but the total running time of the apparatus is correspondingly increased if a reasonable length of film is to be exposed, e.g. ten feet of silent 16 mm. gauge film is run through a projector in twenty-five seconds; if a "time-lapse" camera is set to speed up a movement 10,000 times (which would be quite reasonable when studying, say, the growth of a plant), it would have to

record one exposure every $10\frac{1}{2}$ minutes. At this speed, it would take about seventy hours to produce the ten feet needed to last twenty-five seconds on the screen.

Speeding up a cine-camera is far less easy and requires a specially designed mechanism, unless the increase in speed is relatively low. Many cameras are built to operate at "slow-motion" speeds of sixty-four pictures per second and a few will run at up to 300 per second. The latter speed provides an image moving at less than one-sixteenth of the rate of the subject. Such speeds can be obtained without the film being torn or scratched, but much higher speeds are needed to analyse really fast movements and the film will not then stand intermittent motion.

At this point it should be explained that the film in an ordinary cine-camera is propelled in a series of jerks. While the camera shutter is open to record each individual picture, the film has to remain stationary, and must therefore be quickly pulled through the camera between exposures. This movement is carried out by a claw, which engages in the perforations at the sides of the film, or by an intermittently rotating sprocket. The film cannot withstand such treatment at very high speeds, therefore on all high-speed cine-cameras the film is smoothly and continuously pulled through without a series of "jerks". The film is, of course, moving while each exposure is being made, which would normally lead to a blurred record. The problem is avoided by two methods—(a) by reducing the exposure sufficiently to achieve sharper results or (b) by a method of optical compensation. If the former course is adopted, the exposure time must be very short to compensate for the high speed of the film across the image plane. In such a tiny image, a minute movement during exposure will produce noticeable blurring in the subsequent projected enlargement on the screen. A gas-

discharge lamp flashing at the required picture frequency will give good results but it must be used in a darkened room and the flashing frequency is limited by the characteristics of the lamp.

Most commercial high-speed cameras utilize method (b)—that of some form of optical compensation. The image is held in a stationary position relative to the film by optical means during the period of each exposure. This can be achieved quite simply by moving the camera lens parallel to and at the same speed as the film during exposure. To avoid a reciprocating movement, a number of matched high-quality lenses, as many as twenty-four, are mounted on the periphery of a disc geared to the film drive. This rotates in front of the camera, so that each lens in turn occupies the position of the single lens in a normal camera. A slit between the lens and the film enables the latter to be exposed as the image falls from the lens through the slit. Thus, during each exposure the lens, the image it casts and the film all move together, producing a sharply defined picture. Such cameras have been run successfully at speeds up to about 3,000 pictures per second.

Another type of compensator consists of a glass block which rotates between the single stationary lens and the film. This block is of such thickness and refractive index that, as it turns, the beam is deflected sufficiently to keep the image moving with the film. Cameras employing this type of compensator have reached speeds of over 6,000 pictures per second on 16 mm. film, resulting in the slowing-up of movement about 375 times; at this speed a watch takes about two minutes to tick once. Still higher speeds (millions of pictures per second) have been reached by employing specialized experimental cameras, much too complicated to describe here.

There are, therefore, a number of photographic tech-

niques which can be utilized for the analysis of movement. The method used depends upon the problem to hand. It may only be necessary to examine the movement of the subject at a certain stage, in which case a single high-speed flash photograph will suffice, triggered off at exactly the desired point. In this way the performance of many varied makes of machine has been examined as, for example, the manner in which the shuttle of a loom carrying the weft thread with it travels across the "shed" formed by the warp threads. These records can be made to show finer detail than is possible in cine-films, and have proved of exceptional value in the weaving and spinning industries for the examination of yarn and thread detail while running through machines at high speeds.

Where interest is shown in displacements, a double exposure will often provide the required information. Thus two consecutive flashes on a single negative will show the parts which have moved between the flashes and the distance covered in that interval. A similar technique was used during the war to detect slight movements of camouflage, etc. Two photographs were taken under the same conditions on successive days, or weeks. These would normally appear identical to the eye, but when the negative of one was placed upon the print of the other the slightest displacement of any part of the image stood out clearly. Camouflage which could not otherwise be detected might well be discovered in this way, as it is usually impossible to replace it in exactly the same position after removal during alterations to a site. This "superimposition" method of detecting displacements is mainly of value in cases where a long-term interval has elapsed, though it has been used in high-speed records to estimate the effects of vibration and other small displacements.

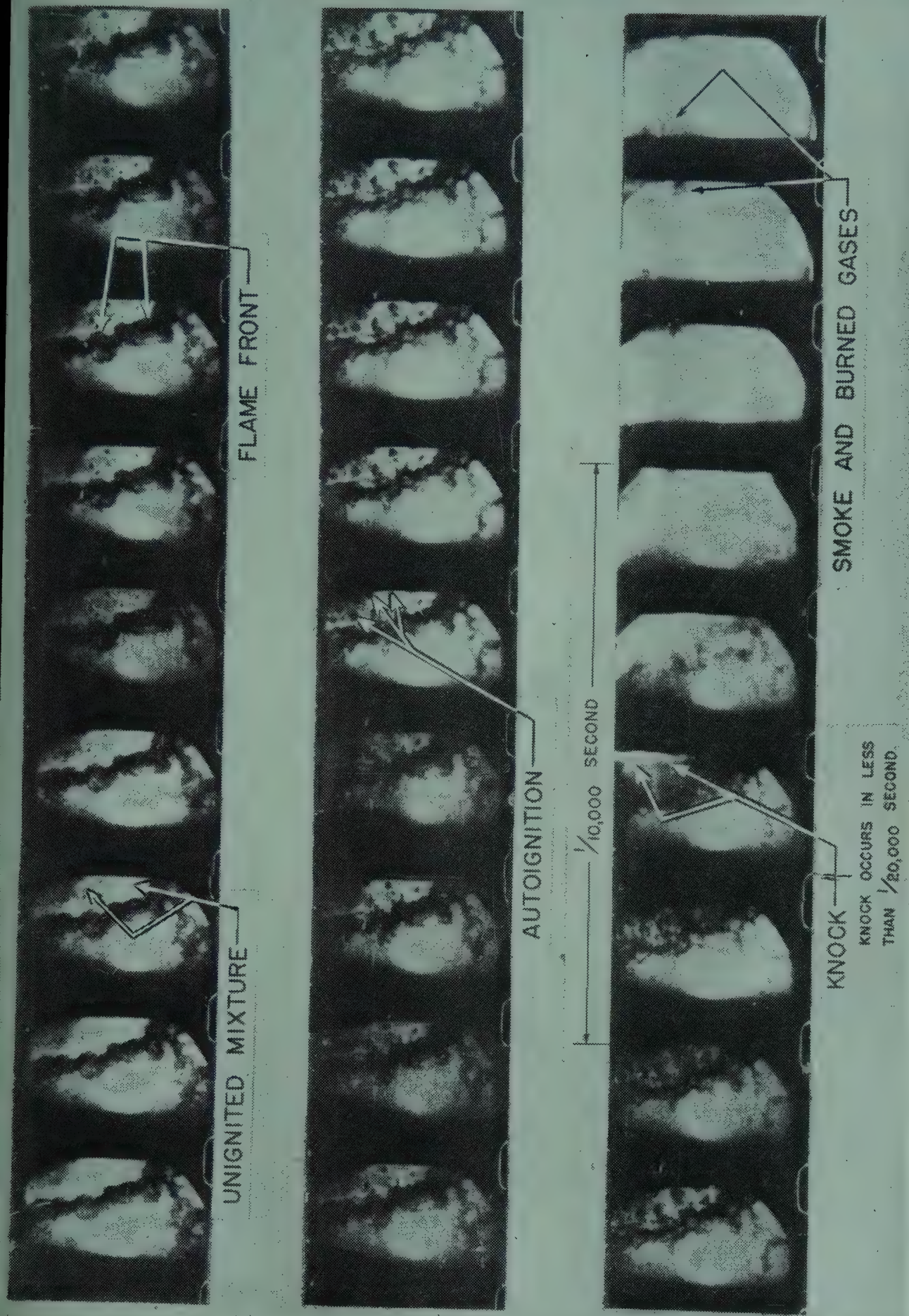


PLATE XV

Courtesy: National Advisory Committee for Aeronautics

A series of high-speed photographs taken with a special camera by C. D. Miller. This camera records the explosion inside an internal combustion engine cylinder through a window in the cylinder block.



PLATE XVI (a)

Courtesy: Royal Aircraft Establishment

A jet atomizer in action, as recorded by high-speed photography.



PLATE XVI (b)

Courtesy: National College of



Three consecutive frames from a high-speed cine film of the action of a watch escapement, showing one of the pallet stones in contact with a tooth of the escapement wheel.

Another method of analysing vibrations is extensively used for determining the velocity and direction of all kinds of movements. This consists of attaching a small source of light at each point of interest so that the subject traces its own path on the photographic plate. This necessitates the use of the camera in a darkened room and entails exposures long enough to cover at least one cycle of the movement. This technique has been widely used in the form of the chronocyclegraph employed for motion study of machine operatives. Small pea-bulbs at the ends of light cables are attached to the hands, elbows and any other moving parts of the body. The operative then works normally and an exposure is made covering one or more cycles of the operation. The exact path of the hands, etc., can be followed in the resulting record, which often reveals considerable wastage of effort. In addition, the application of a saw-tooth oscillation to the current supplied to the lamps will enable the velocity and direction of the trace of each movement to be determined. Such records are of particular value for comparison of methods before and after the application of motion study techniques. Special methods of filtering have been invented to permit the operative to work under natural conditions of lighting. For example, infra-red materials are extremely sensitive to the light from pea-lamps, which is abundant in red and infra-red radiation. An infra-red filter over the camera lens therefore enables the operative to work under bright greenish lighting containing no appreciable amounts of infra-red radiation, only the light from the pea-lamps being recorded.

“Trace” or “streak” pictures of this type give little or no indication of the visual appearance of the subject—only the trace of the subject’s movement is recorded. This is sometimes insufficient and a record of the subject

repeated at short intervals is required. This can be provided by the use of a cine-film which, if desired, can be viewed as a series of consecutive still pictures, but it is often more convenient to examine the separate images recorded on a single print. This result can be achieved by using an ordinary camera in a darkened room, and firing a number of flashes from a gas-discharge lamp while the shutter remains open. For the best results a black background should be used. Gas-discharge lamps can be made to flash over a wide range of frequencies and hence the time interval between exposures can be adjusted to give any desired picture-spacing for the velocity concerned. This technique has been used by Gijon Mili and others to produce exquisite pictures of ballet dancers, acrobats, athletes and similar performers. It has also proved to be useful in analysing the detailed movements of athletes and animals, including the flight of birds, bats and insects.

A typical example which shows its full value is that of the analysis of the swing of a golf club. The flashing lamp is set to give, say, fifty or sixty exposures throughout the swing, and the resulting print shows a superimposed multiple image of the golfer, with separate images of the club surrounding him in a circle. In each case the position of the face of the club, the reaction of the shaft and the grip of the player's hands can be seen. In those exposures covering the period from the impact of the club and ball to the time when the latter leaves the picture, the course and any spin of the ball can also be examined. Finally, since the lamp flashes at regular intervals, the spacing of the images can be used to decide velocity and acceleration at each part of the stroke.

For such work, a single photograph containing all the images is easier to measure than a series of images on separate pictures, as in a cine-film. There are, however,

few investigators who do sufficient work of this nature to justify the need for a flashing gas-discharge lamp of the power needed. Thus a cine-camera is sometimes employed instead. This aspect of motion analysis with the aid of a cine-camera is of considerable importance, for measurements made on the individual "frames" of the film are often of more value than the most careful observation of the moving picture on the screen.

The method usually adopted in the analysis of movement is to approach the problem stage by stage. The subject is first photographed with a high-speed cine-camera and the film projected. This enables the general features of the movement to be observed. The subject may be merely a blur, or actually quite invisible to the eye, but a preliminary study of this nature ascertains the general order of its velocities and displacements. A decision is then made concerning the individual portions of the subject to be analysed in detail, the angle of view and lighting required to show each to best advantage, whether "flash" or high-speed cine-camera is to be used and the required camera speed and exposure time. These operations are then completed and the conclusions recorded in the form of velocity and displacement figures or graphs. Where the method is being applied to machine analysis, these figures are used to enable a detailed re-designing of each moving part to be carried out. After every modification, further photographic work is needed to determine the effect of re-designing until each part operates in the most economic manner and in harmony with its neighbours.

It is surprising to discover the amount of undesirable movement which occurs in parts of high-speed mechanisms, much of which a designer could not foresee. Even the most robust machines, recorded when under severe shock,

frequently appear to behave like jellies. Vibration often introduces much greater relative displacement than is realized and moving parts may travel about in a way which would be considered quite impossible if photographic proof were not available. Though they occur even in large machines which move relatively slowly, such unexpected movements are a particular feature of small, light articles such as switchgear, electrical relays, typewriters, motor-car equipment and light automatic weapons. The effect of the explosion of each cartridge on the loading mechanism of light machine-guns was closely studied during the early stages of the Second World War, resulting in the production of several amazing film records. The behaviour of some of the older types of telephone relay was quite remarkable, high-speed films revealing much unexpected bounce and chatter. In addition, surging in motor-car engine valve springs, and the action of camshafts and timing gear, have also been studied. Some of the more interesting records show the growth of the explosion inside an engine cylinder, and have given useful information on "knock" and similar detonation troubles. Other typical applications in the motor-car industry include the recording of the action of road springs and shock absorbers, the performance of tyres on rough roads and over broken glass, nails, etc., carburettor action and diesel engine atomization, Bendix starter action and the behaviour of door catches.

In practically every industry a list of similarly diverse applications can be compiled, though such industrial applications rarely require the shortest flashes or the highest film speeds. Velocities involved are usually moderate and require slowing-up at the most about 200 times. This necessitates employing a camera speed of around 3,000 pictures per second, equipment for which is small and easily transportable. Greater speeds

are needed for some ballistic applications and for this purpose it has proved easier to produce a very short-duration flash than a high-frequency film camera, largely because of the inherent mechanical problems of the latter. Because of this, excellent "still" photographs of bullets in flight have been obtained for many years. It is, however, only comparatively recently that films have been made of such high-speed phenomena as bullets leaving a rifle barrel.

High-speed photography is being used increasingly in research into the field of ballistics and armaments. This has led to the development of highly specialized cameras, most of which are of little use for other purposes. Without going into a detailed explanation of such cameras, the ingenious principles on which some of them work may be of interest, as more revolutionary ideas are probably employed in this field than in any other branch of photography.

Although it is not difficult to produce short-duration flashes by means of an electric spark, there is a lower limit of $1/2,000,000$ th of a second (half a micro-second) or slightly less to their duration, though even this requires a special circuit with low-inductance condensers fitted with the shortest possible leads. A spark can, of course, only be used as a light source for recording in total darkness, whereas some projectiles must be recorded on outdoor ranges. This problem has been partially solved by the use of the Kerr cell shutter, which is a cell of transparent liquid (usually pure nitrobenzene) containing a pair of electrodes. This liquid rotates the plane of polarized light when a high-voltage pulse is applied to it. Thus if two polarizing filters are placed in the "crossed" position with the cell between them, they will normally transmit practically no light. If, however, a short pulse

is applied to the electrodes, the plane of polarized light transmitted by the first filter will be rotated as it passes through the liquid and the second filter will then transmit it. The device is placed over a camera lens and acts as a shutter which will give an exposure as short as the duration of the pulse applied to it. This can be $1/1000$ of a microsecond or less. If desired, circuits can be devised to repeat such exposures at high frequencies.

Unfortunately, a Kerr cell shutter requires the use of high intensity lighting because of the short exposure time. This difficulty has now been overcome by the use of a recently devised high-speed image converter. An image converter consists of a light-sensitive cell which receives an image and emits electrons, these being accelerated by high voltage on to a luminescent screen, thus reproducing the image visibly. Such tubes have been used to convert infra-red images into visible pictures. As the tube only works while the high voltage is applied, it can be made to provide a high-speed record by applying a short high-voltage pulse, as in the Kerr cell technique. The light-sensitive cell receives an image of the moving body all the time. At the selected instant, the pulse is triggered and the luminescent screen records the moving image during that period. A screen with a long afterglow enables the image to be seen with the naked eye, but photographic material will record it permanently.

As the cell is very sensitive, it does not require unusually high light intensity for it to operate; moreover, the lighting required is not determined by the exposure time, as in photography. The brilliance of the screen photographed by the camera can be varied, within limits, to allow the camera to record it in the short time available. The method has certain disadvantages—as the screen is never very bright, it is difficult to obtain a good record

during the shortest exposure times. Moreover, the screen is grainy, so that the images lack detail. But the principle is of considerable interest and further developments can be expected.

The problem with cine-cameras is to achieve a sufficiently high picture frequency without increasing mechanical troubles. This usually has to be achieved by the sacrifice of some fundamental quality in the film. Apart from picture definition, which is invariably affected, the spacing of pictures along a strip of film may have to be irregular. Again, the total number of pictures so recorded usually has to be substantially reduced. The final result is thus likely to be a series of, say, fifty pictures on a plate, not arranged in consecutive order and possibly not all the same way up. It is, therefore, almost impossible to print such a record as a cine-film and, even if it were, it would be projected for such a short time on the screen that it would be difficult to study. Hence almost all so-called cine-cameras working at speeds above 10,000 pictures per second produce records which are studied as still-picture sequences. Their value is rarely, if ever, diminished by this type of sequence, especially as some of them enable frequencies as high as 100,000,000 pictures per second to be achieved.

The methods by which such extreme frequencies are reached are diverse and complex. In all cases, something more than mere speed of shutter revolution is needed. As an example, the Marley camera relies upon a vernier system which provides a much higher rate of picture-taking than a simple revolving shutter driven at the same shaft speed. Two co-axial discs are used, one stationary and the other revolving in close juxtaposition. Each disc contains a number of apertures cut near its periphery. The rotating disc contains one more aperture than the

other, while behind each aperture in the fixed disc is a small camera. As the rotating disc moves, the apertures in it uncover those in the fixed disc. The difference in number of apertures causes only one camera aperture to be uncovered at any one time but the rate of exposure is much higher than the speed of rotation of the disc—in fact, all the camera apertures are exposed in the time it takes for any single aperture in the rotating disc to move to the succeeding position occupied by its neighbour. Thus, if there are fifty apertures, the total record will be completed in about $1/50$ th of a revolution. This will enable fifty pictures to be taken at a frequency of 25,000 per second, assuming that a shaft speed of 30,000 revolutions per minute is employed. Care has to be taken to allow the apertures to be uncovered for one revolution only, to avoid double exposures. This is achieved by a third “capping” disc which allows all the cameras to operate during only one single revolution of the moving disc. The phenomenon to be photographed must be arranged to take place during the $1/500$ th of a second required to make the fifty exposures.

Other ultra-high-speed cameras operate by means of a rotating mirror which diverts the image of the object through a series of lenses in succession. There are a number of optical systems of this type, all complex, and becoming increasingly so as the picture frequency rises. One ingenious method, based on an entirely different system, is known as multiple-aperture focal-plane scanning. This enables a number of pictures to be exposed on a single plate with a minimum of movement. To understand the principle it is necessary to visualize a grid comprised of a large number of alternate opaque and transparent bars, the latter narrower than the former. If this is placed in contact with a photographic plate of equal

size it will act as a mask. If a picture is exposed while it is stationary, transparent spaces corresponding to the opaque bars will be seen across the resulting negative. If, however, the grid is moved in a direction at right angles to the bars, so that they move bodily sideways, the whole plate can be exposed in a series of steps. The number of steps depends upon the ratio of the widths of the transparent and opaque bars, the total possible movement of the grid being equal to the width of the opaque bars, since any further movement will over-run the vacant space on the plate and produce a double exposure. Thus if the opaque bars are five times as wide as the transparent ones, five pictures can be made on the one plate by five sideways movements of the grid each equal only to the width of the opaque bar. It has been found in practice that these exposures do not need to be made separately. If the grid is moved steadily through the correct distance, the blur produced on the final record can be satisfactorily synthesized into the corresponding pictures when a similar grid is placed over it to select the necessary strips. Naturally, this method is satisfactory only when the bars are extremely narrow. The redeeming feature of the method is that the naked eye is satisfied with the picture even when the transparent bars are much narrower than the opaque ones, provided of course that they are close enough together. A ratio of 30 to 1 still gives a recognizable picture with fairly fine grids, thus enabling thirty pictures to be taken on the one plate, although each individual image consists of only $1/30$ th real picture and $29/30$ th empty space! Thus thirty records can be taken in as short a time as the grid can be moved through the required distance of $1/50$ th of an inch. The individual pictures have to be separated later by re-photographing the smear record thirty times in succession, moving the grid across it a section at a time.

Almost all cameras giving the picture frequencies attainable by these specialized methods are used in armaments research. They enable the explosion of charges, the path of projectiles, the behaviour of rocket motors and similar subjects to be examined in detail. A principle similar to that used in multiple-aperture focal-plane scanning is, however, used in one application which requires far lower speeds, namely race-finish recording. Photography has always been useful in assisting judges to determine the final result of athletic, horse or dog races. Originally, single still photographs were taken along the finishing line. Later, cine-cameras were used, leading to the use of electric slow-motion cameras linked to a clock which not only showed the winner but also the duration of the race. Such cameras were used at the 1933 Olympic Games at Los Angeles. The present type of race-finish camera, however, employs a focal-plane scanning principle which has the advantage of being a continuous record giving the exact order in which contestants pass the winning post. Such cameras are now in use at many racecourses and were employed at Wembley during the Olympic Games. They are an invaluable aid to the judges, though their use has caused doubt in the minds of the public, due largely to the curious appearance of the contestants, the absence of any normal background, and the fact that the "winning line" has to be drawn in across the front of the leading runner after the end of the race. These peculiarities are due to the fact that the record shows the runners as they pass a point and not at a particular instant in time, as a normal photograph does. This is difficult to visualize and the general public can, perhaps, be pardoned if they regard such explanations with scepticism. A description of the camera may make, however, for easier understanding.

The lens is set to cast an image on a vertical slit in the back of the camera. The line of view is laid accurately along the finishing line from high up, so that an oblique view from above is obtained of the finish of the race. The camera can thus "see" only a thin vertical slice of space rising from the finishing line. As the runners approach, the film is run across the slit in the back of the camera at a speed roughly equal to that of the image of the runners and as the latter cross the line, they cross the field of view of the camera and are exposed, through the slit, on to the film. As each successive part of each runner crosses the field of view it is recorded on the corresponding piece of film. Thus the film accurately records the sequence of events at the finishing line but the final records are given an odd appearance. As the background is stationary, it does not appear on the record, having been drawn out into a streak. If the film is run too fast the runners are elongated, if too slowly they are dwarfed. Limbs take on unnatural attitudes; for example, the hind legs of a dog may be forward as the fore legs pass the line and are recorded, but may point backward as they themselves are recorded an instant later, the final record showing the dog in an impossible position. Nevertheless, the sequence of passing the post is always correct, the only possibility of error being when two runners are so close, side by side, that even the elevation of the camera cannot separate their limbs and part of one runner is usually mistaken for part of the other.

It is curious that there are a considerable number of applications of high-speed photography, while those of (the technically easier) time-lapse recording are very few. There appear to be many more rapid motions we wish to slow down than slow motions we need to speed up, and

the method may also be restricted by the expense of keeping a camera in use for extended periods of time.

The growth of plants is a typical subject to which time-lapse photography has been usefully applied. Popular appreciation of the results which can be achieved by careful work in this direction is, however, probably attributable (in Britain) to the inspiration of one man—Percy Smith, who devoted many years of painstaking work in order to achieve technical perfection. Satisfactory results in the study of plant life necessitate the most careful control of the conditions under which they grow, and to be able to control the lighting to suit both growing conditions and the photographer during exposure times.

Another subject which has proved suitable for time-lapse study is the movement of clouds. Films have been taken to portray cloud movements over a particular point during a whole day, illustrating the changes of wind and other meteorological changes as the sun slowly rises to its zenith and sinks again below the horizon. One other interesting application is the illustration of operations which take a considerable period of time to complete. A film for training land-girls during the war, for example, demonstrated the way to plough a field. The actual ploughing took a whole day to complete but it was considered inadvisable to show only part of the work involved as the pattern followed by the plough and the method by which the sequence was built up were equally important. A film was therefore made in which the whole of the day's work was speeded up and condensed into half an hour of film time. The tractor with its plough, careered about the field like a racing car but all the finer points of the technique used were demonstrated in a time short enough to fit into a lecture period.

Photography is being used on an increasing scale to

analyse movement. It provides a certain, speedier, and easier method of examining most movements than any other available technique. Motion, in one form or another, is of importance in almost every human activity, and the potentialities of photography in this direction are probably much greater than its present use would indicate. Although it is fairly widely used as an aid to fault detection in engineering design and in the study of athletics and animal movement, it has still a very much wider potential. The technique is by no means difficult, but a greater realization is required of the benefits to be gained. In the United States of America, where both athletic prowess and the constant improvement of machinery are taken rather more seriously than in Britain, photographic analysis of movement is used to a greater extent. Wider use of this technique would undoubtedly assist British industry to achieve a much-needed increase in productivity in the mechanized industries.

PHOTOGRAPHY IN PRODUCTION

IN PRECEDING chapters, photography has been shown as a means of recording, either for filing or for investigation. In some cases, however, it is used as an integral step in manufacturing processes. The best-known example of this form of application is found in the printing industry. The great majority of illustrations used in books, magazines and newspapers trace their origin from photographic prints. Even the printing process itself often incorporates photographic processes.

The three main methods of printing are known respectively as letterpress, lithography and gravure. Although these methods were originally non-photographic, all three now involve the use of photography. The letterpress process uses it least, as the written matter can be set by Monotype or Linotype machine and by hand. Blocks for reproducing the illustrations are, however, made by a photographic process. A light-sensitive layer (usually a bichromated glue) is coated over a metal surface and exposed behind a negative of the illustration. Since the printing process can reproduce only black or white, grey or half-tones have to be simulated by a pattern of dots, which is introduced when the negative is made. These can be seen if any letterpress illustrations (such as the ones in this book) are carefully examined. Exposure of the bichromated layer behind the negative renders the exposed portions insoluble in water, the remaining (unexposed) portions being washed off to expose the metal

beneath. By suitable treatment, the image is transformed into a resist through which the metal can be etched with acid solutions. The final plate then consists of raised portions, which receive ink in the same manner as the type, and the sunken or etched portions, which do not. This plate is mounted on a base to raise its face to exactly the level of that of the type with which it will be printed.

In lithography, there is no difference in the height of the surface of the plate. Instead, the image portion of the plate is made to accept greasy ink, while other parts are treated to repel it. This can be done mechanically with a greasy crayon, but more usually a light-sensitive layer is spread over the metal and exposed behind a negative, a dot pattern being used for half-tone illustrations. In this case, a negative must be prepared for all type matter, and this is incorporated into the plate in the same way as for the illustrations. Text matter is set letterpress, a clean proof is then taken and photographed to provide the negative. After exposure, the resulting plate is washed as before, and treated to make the exposed portions ink-receptive. This system is used to provide printing plates for certain small office printing machines as well as for the larger commercial machines, as negatives can be made direct from typewritten, handwritten or drawn originals. Recent developments have provided printing plates for such machines made of paper or a plastic material in place of metal and which are sensitized with a silver halide layer. These are cheaper, easier to handle and require less processing equipment than the metal sheets.

The photogravure process involves the use of a somewhat similar method, though the surface of the plate is uneven. It contains depressions which are filled with

ink, the raised surface of the metal being scraped clean after each application. When a sheet of paper is applied the ink is transferred to it from the depressions. The system is thus, in a sense, the reverse of the letterpress system, in which the ink is transferred from the raised surface of the plate, the hollows remaining clear. Gravure plates were originally engraved by hand but photogravure enables the plates to be prepared mechanically. Instead of coating the plates with a layer of sensitized material (a method common to other processes) a material known as carbon tissue is used. This is a sheet of paper coated with bichromated gelatine exposed behind a positive transparency made from the original negative. After exposure, the tissue is placed face down on the surface of the printing plate, to which it adheres. Hot water is then applied, allowing the paper to be stripped away and leaving the image in hardened gelatine on the metal. This is used as a resist to control the etching process.

In the above printing processes, light-sensitive materials have been used for many years, and during this time skilled craftsmanship has built up first-class techniques which are subject to little change. Originally operatives used collodion plates, which had to be prepared before each exposure and loaded into the camera in a damp state, whereas excellent results can now be obtained by the use of modern gelatine dry plates. Wet collodion plates are slowly being replaced by dry plates, while the latter are firmly established for purposes and processes where they are generally agreed to be more suitable, such as photogravure, which is being employed on an increasing scale. Beyond this, however, are signs of a still greater step towards the use of gelatine-silver halide emulsions in place of the bichromate-sensitized gelatine (or glue) layers now

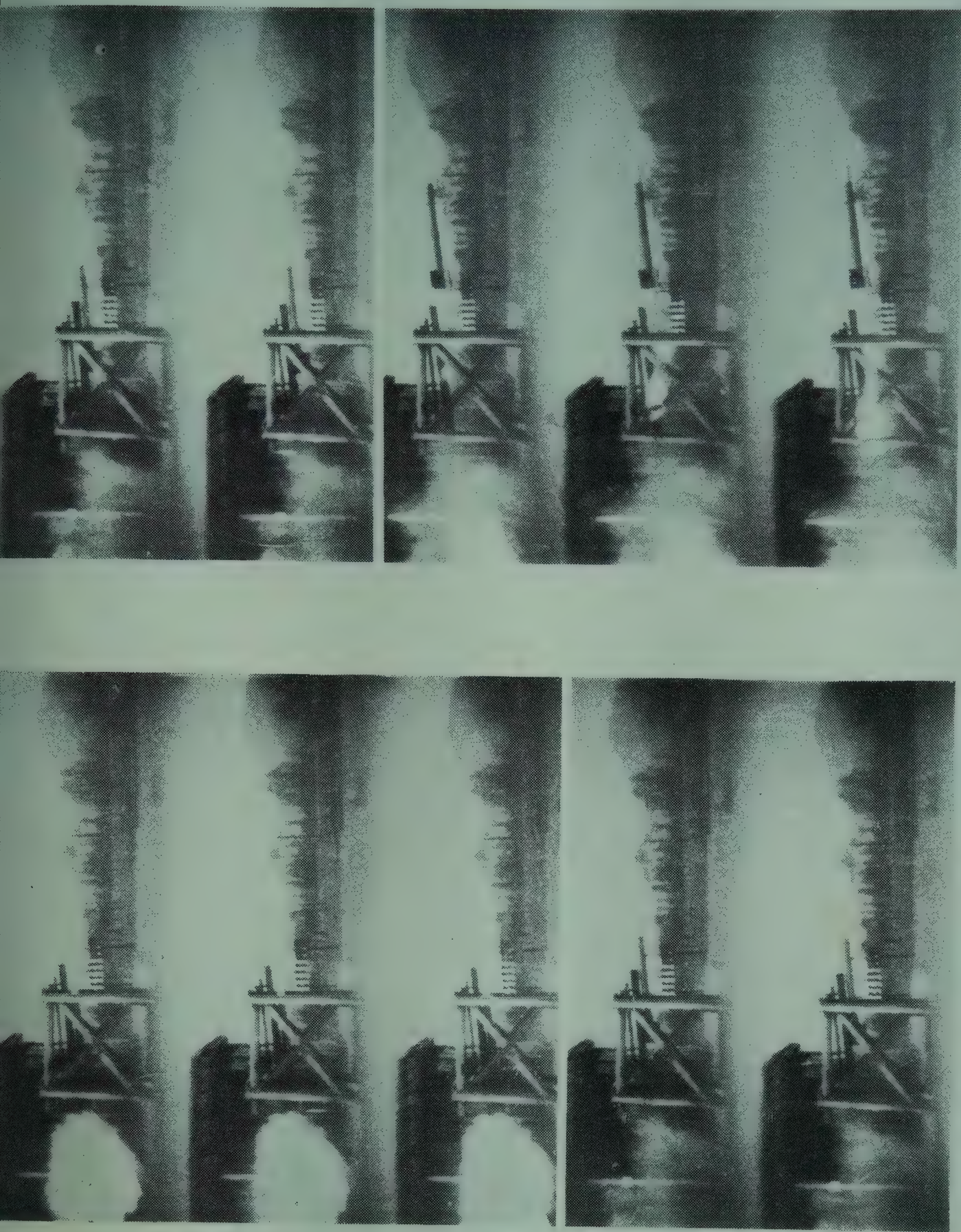


PLATE XVII

Part of a film showing the launching of a rocket travelling at 1,000 ft. per second. A Fastax camera was used, running at 3,500 pictures per second.

Courtesy: Wollensak Optical Co.



PLATE XVIII

Crown Copyright

An aerial photograph of Caen taken during the Battle of Normandy. Many photographs of this type have been reproduced before, but they are usually on too small a scale for the detail in them to be appreciated. The area outlined in white in the top picture is shown enlarged (right) to illustrate the wealth of detail recorded. The damage to the bridge is clearly visible.



generally employed on printing plates. Such processes are as yet only in their infancy and it will no doubt take many years to perfect and install them. They assist the operator by replacing hand coating of the plates with machine coating, a less laborious and time-wasting method and one which produces a better result.

Another technique used by the printing industry is that of teletransmission for sending illustrations by telegraph or radio. This relies upon the use of photography even for the sending of non-photographic illustrations. In order to convert the picture into a series of electrical impulses which can be transmitted to the receiving station, it is scanned by a small dot of light. The picture is wrapped round a cylinder mounted on a screw, the pitch of which is equal to the width of the scanning spot. Thus as the cylinder rotates steadily, so it moves along the thread of the screw and the spot of light scans the whole picture in a spiral. An image of the illuminated spot is projected on to a photo-electric cell, which responds according to the brightness. Thus when a light portion of the picture passes through the spot a strong signal is sent out and when a dark portion is scanned the signal is correspondingly weaker. At the receiving end a similar drum, which is synchronized to rotate with the transmitting drum, carries a sheet of photographic paper on to which a corresponding spot of light shines. This light is controlled by the power of the incoming signal, so that the paper is exposed to a greater or less extent by the light as it varies with the incoming signal. Thus a picture is built up as the spiral exposure progresses until the sheet is fully exposed and, when developed, produces a replica of the original, provided that no electrical disturbances have interfered with the transmission. The detail recorded is limited by the size of the scanning spot but this can be

very small, so that the result is hardly distinguishable from the original.

A branch of printing in which photography is widely used is that of map-making. Maps are hand-drawn and reproduced by lithography. To avoid re-drawing the originals each time a slight alteration is necessitated by the making of new roads, building or re-afforestation, special photographic materials have been manufactured for making negatives, upon which alterations can be inserted by means of a tool with a fine point. The need for re-drawing or re-photographing the originals is thus avoided and the corrected negatives are used to make a new set of printing plates.

Photography has, however, a far more important use in map-making; that of the preparation of aerial mosaics from which maps can be made with a minimum of ground survey. The convenience and speed of aerial mapping have encouraged research into means by which its accuracy may be improved. Considerable experience was gained during the Second World War and a very high degree of accuracy can now be obtained—probably higher in the case of inaccessible country than with conventional ground surveying. Improved methods have also resulted in considerable savings in cost.

The area to be mapped is covered by the aircraft flying to and fro in a series of lines while taking vertical photographs. The lines of flight and exposure intervals are arranged so that there is a considerable overlap (usually about 60 per cent.) in adjacent photographs. The overlap along the line of flight is greater than that between one line and the next. In fact, the overlap in the latter is almost dispensed with by using the latest methods, which control the position of the aircraft and the moment of exposure by means of a radio link based upon radar

plotting of the course. This technique enables aircraft to be sent back to complete any small gap in the collection of negatives, caused by, perhaps, an isolated cloud or technical trouble. Only a few pictures are now required as against the larger number previously needed to ensure complete coverage of such gaps when the older methods of navigation were used.

A mosaic is produced by mounting the photographs carefully together. This presents a picture of the ground from above, and is useful in this form, though it can also be used as a basis for conventional maps. Small errors introduced during flight by variations in the height or attitude of the aircraft have to be corrected, and it is necessary to check the accuracy of scale in the two dimensions against a few master measurements on the ground. Such mosaics are of particular value in providing specialized information on cultivation of the land, types of vegetation and rock formations. The maps so produced can be contoured by means of stereo examination.

Stereo photography has received brief mention in earlier chapters. It is a technique which has great possibilities yet seems to be seldom used apart from its application to aerial survey. It is based on the well-known principle that the eyes perceive depth because of the slightly different view each receives. A pair of photographs taken from different angles, and viewed in such a way that each eye sees only its appropriate view, will provide the impression of viewing in depth. If the photographs are taken with an angular separation corresponding to that of the eyes, the depth will appear normal but as the separation is increased the effect will be exaggerated. This procedure is adopted in aerial survey, because details such as relief can hardly be appreciated from the height at which the aircraft flies.

It was mentioned above that each pair of aerial photographs overlaps considerably. This enables them to be viewed as a stereo pair, by means of a suitable optical device. Between the recording of one picture and the next, the aircraft moves considerably farther than the distance between the human eyes. The stereoscopic effect is, therefore, correspondingly enhanced and even shallow ditches, walls and trees can be seen in relief. In practice, elaborate equipment enables an aerial image of the topography to be projected and this is measured as if it were a solid model, thus enabling heights of trees or buildings, contours of the land and other height measurements to be plotted.

The applications of aerial survey to fields other than that of pure mapping should not be ignored. In the United States of America, the aerial surveying of ground over which roads are to be built has enabled the amount of soil to be moved and the weight of concrete needed to be calculated more cheaply and quickly than by established methods. One fascinating application of aerial surveying is that of archæological work. The sites of ancient buildings, earth-works or roads are often revealed by aerial photographs (taken at certain times of the year) owing to a slight difference in the height or colour of the vegetation covering them and quite imperceptible from the ground. It is recorded that two days of aerial survey, carried out a few years ago, added more to our knowledge of Roman Britain than the previous two centuries of archæological research.

Apart from peacetime surveying, aerial reconnaissance is of great importance in time of war. Aerial photographs are unfamiliar in appearance and therefore not easy to interpret, though a skilled interpreter can obtain from them a vast amount of information. During the

1939-45 war, special organizations were set up by the Allies to deal with aerial reconnaissance and these provided a large proportion of the total intelligence information received. Millions of photographs were made over enemy territory and each examined by a number of experts in different fields. By 1943 the route and cargo of every enemy vessel of importance was being recorded day by day. Every industrial activity in enemy occupied territory was watched and even the output of the principal factories calculated. When these figures were subsequently checked they were found to be remarkably accurate. Research on flying bombs and other weapons was closely watched and steps taken to retard their manufacture and launching. Aerial photographs were also used to provide detailed information of the Normandy coast in preparation for the subsequent "D" Day landings. These photographs were, in many cases, used for briefing purposes, an oblique angle of view being employed to provide sea-borne troops with the appearance of the coast they would expect to see when landing. Almost perfect models of certain ports were made from such photographs prior to Commando operations and thus undoubtedly had much to do with the success of many of the raids. By the time the men landed they were thoroughly familiar with the terrain to be covered, although they had never been there before.

A similar technique, which was also improved during the war, is that of "terrestrial photogrammetry" by which the dimensions of buildings are deduced from photographs. During the war, the National Buildings Record was established in Britain to collect photographic records of historic buildings in order to preserve details if they were destroyed by enemy action. A number of bombed churches and other buildings have been rebuilt to exactly the same specifications from photographic records, no

drawn plans being available. Although useful measurements can be made from any clear photograph, proper photogrammetric records, from which full and accurate plans can be produced, require careful and specialized technique. Very little attention has been given to this subject in Britain, though it is appreciated more widely in other countries. A similar technique applied to engineering has facilitated decisions on the fitting of aero engines into nacelles of limited dimensions. By using stereo records, a three-dimensional aerial image can be manually "fitted into" a model of the nacelle. Stereo cinematography has been possible for work of this sort for a number of years and interest in it has been revived by the Telecinema at the Festival of Britain. It has found few applications, however, partly owing to its technical complexity.

Possibly the largest single use of photography in industrial production is that of the photo-template system. This provides a method of transferring a scale drawing directly to a metal, wooden or plastic surface, with considerable dimensional accuracy, thus eliminating the laborious and costly stage of hand-scribing from a dimensioned drawing. The use of this technique is said to have saved up to six months in the time taken to reach the first flight stage of an aircraft of new design. It has also been used to a smaller extent in car manufacture.

A template is a pattern used to make larger numbers of similar parts. Some of the more elaborate types in the aircraft industry require hundreds of man-hours to scribe from drawings, and a number of identical ones may be needed, thus multiplying the work involved. The photographic method involves the use of dimensionally correct drawings, usually on white-lacquered metal to prevent the introduction of inaccuracies by atmospheric

changes. These drawings are photographed and the negatives printed on to template metal coated with a layer of photographic emulsion. After processing, the template can be cut, drilled, milled and pressed to the required shape, as indicated by the lines on it. An accuracy of $1/1,000$ th of an inch per foot is attainable. Modern aircraft may contain over 30,000 separate sheet metal parts, each of which should be constructed with sufficient precision to enable it to be interchanged if required. The photographic method not only saves a considerable amount of time by replacing hand-scribing but also ensures that the templates are marked out identically, to a high degree of accuracy. Estimates have been made of the savings involved, which range up to about £5,000 per aircraft. Similar methods are also applicable to the motor-car, shipbuilding and furniture industries, though at present only limited use appears to have been made of them.

The adaptability of the photographic process is well illustrated by the modifications which have been introduced into the template application. Alterations in scale can easily be made, though, normally, the original drawings are reduced to about one-quarter scale on the negative, which is then enlarged to the exact original size. If desired, however, a slight adjustment to the enlarger will allow for small differences in scale made necessary, for example, by shrinkage of the metal during a fabrication process. Similarly, enlargements can be made to an entirely different scale in order to produce a perfect model of the aircraft at, say, one-eighth scale.

Again, if the original drawing contains certain lines in different colours the particular set of lines required can be selected by means of a filter placed over the camera lens. Thus, hydraulic equipment might be blue, electrical

wiring red and the external outline of the section concerned, black. By the use of a panchromatic plate, all could be reproduced together if no filter was used, while a red filter would eliminate the red electrical wiring and a blue filter the blue hydraulic piping. Photographically reproduced drawings on metal have been used for the actual assembly of wiring and piping. Each part is marked with the necessary directions and location marks to assist proper positioning and connection. This technique has been used also in radio assembly, where a wiring diagram and directions printed on the chassis enable radio or television sets to be assembled and wired correctly by relatively unskilled labour.

The coating of metal surfaces with photographic emulsion is a fairly recent innovation. Many metals cause deterioration of the emulsion and it was at first difficult to achieve a good bond between the image and the metal. Methods have been devised in the last fifteen years by which emulsions can be coated, sprayed or laminated on to metal. Lamination is generally employed by the aircraft industry when applying silver halide emulsions, while the "spray" method is used for other types of sensitive material. Coating is uneconomic because it entails either expensive equipment (in the user's factory) or the coating of large sheets of metal by the photographic manufacturers, thus introducing heavy transport costs.

The emulsion supplied for laminating is coated on to a paper base in such a way that the two can be easily stripped apart. "Stripping papers" have been made for many years, the technique being to expose and process the paper first, fix it to its final support, and finally to strip the paper away, leaving the image on the support. In this way, photographs have been used to decorate lamp shades, cushions, frosted window panes and tumblers. The same

method can be used to transfer drawings to metal or other sheet material. It is, however, usual to transfer the emulsion before exposure and processing; this avoids dimensional instability. A sheet of paper changes its size when damped and re-dried, but if the emulsion is attached to a sheet of dimensionally stable material before exposure, the final image after being dried and processed is exactly the same size as the original image. The bond between emulsion and metal (or other material) is, in fact, so strong that no normal mechanical operation will separate them, though friction which generates sufficient heat will char or blister the emulsion, and coolants containing water will cause the gelatine to soften and peel off unless it is first lacquered.

The paper is therefore normally laminated, emulsion surface down, to the metal, which has been first coated with a thin layer of lacquer. Bonding may be effected by a liquid or by heat. The paper backing is stripped away from the surface just before use, leaving a clean, even layer of emulsion on the metal surface. The advantages of this procedure are that the paper can be coated quickly, cheaply and evenly on the normal manufacturing machinery and stored in rolls until required by the aircraft factory. Lamination is quick, simple and certain and the paper backing protects the emulsion layer from mechanical abrasion and light rays. The process is thus considered to be superior to the spraying of an emulsion by means of a compressed-air gun.

Emulsions have been applied by spray gun but the technique is now mainly limited to a cheaper type of bichromate-sensitized layer, and rarely used with silver halide emulsions. These cheaper sensitizing layers need intense lighting to effect exposure and because of the difficulty of obtaining a very high intensity of light through

an enlarger lens their use is largely restricted to contact-printing from large negatives. Such large negatives can, however, be produced by hand-scribing on to glass plates covered with a thin, opaque pigment layer, which is convenient for some types of work. The technique also has the advantage that the image is developed by washing in hot water, leaving very fine lines adhering strongly to the metal but (unlike the silver halide emulsion) with no medium of any sort covering the intermediate surface.

Techniques of this nature have proved useful for purposes other than the production of templates. The images produced by the bichromated-layer method can be fired into the glaze of pottery for decorative or scientific purposes, while the silver halide emulsions can be used for producing all types of measurement scales, dials and name-plates. In many cases the photographic image is not visible in the final result but is used merely as a stencil. For example, a clock dial can be photographed and printed upon a lacquered brass plate covered with an emulsion layer. The image may then be used as a stencil to dissolve the lacquer image-wise, leaving a lacquer face with brass numerals showing through, or lacquer numerals on a brass background. The lacquer stencil can, in turn, be used to silver or etch the brass surface before finally being removed. It is, therefore, possible to obtain numerous combinations of colour and effect.

Photography has been widely used to produce small measurement scales or patterns by similar means. Such minute images are generally known as graticules or reticles. They comprise micrometers for microscopy, particle-size evaluators, gun-sights, eye-piece scales for many scientific instruments, electron microscope specimen grids and microscopic sieves. The methods used to prepare these graticules are similar to those described

above for making name-plates and dials, though the actual techniques have to be adapted to the smaller size of the image. Fortunately, photographic materials are available which are capable of resolving at least 25,000 lines to the inch. The problem in making the finest scales is, in fact, not so much one of choice of material as of selection of equipment. Optical systems capable of reducing drawings from normal sizes to such small dimensions need careful designing and manufacture. The area of high resolution is usually confined to a circle quite close to the optic axis, so that only small areas can be covered by single photographs. The problem is, in fact, the same as that encountered in the copying of documents at a much-reduced scale, dealt with in Chapter 2.

The smallest measuring scales normally produced by photographic means are stage micrometers (i.e. scales on the stage of a microscope for the measurement of specimens) consisting of a millimetre divided into 100 equal parts. The width of each of the lines of such a scale, and the line-width of the numerals along it, are less than $1/500$ th of a millimetre in size but are nevertheless quite clearly defined. The complete scale is almost invisible to the eye but its position is indicated by a heavier line encircling the scale and forming a circle about two millimetres in diameter. A cover-glass is cemented over the slide to protect it. In some cases, the presence of gelatine round the image is objectionable but this cannot be avoided in the smallest scales, though scales with heavier lines can be "washed off" leaving an image on clear glass. Name-plates are dealt with in the same manner. Other methods provide stencils by which the glass can be etched or coated image-wise with a layer more robust than a photographic image. Originally, gun-sights were formed by spiders' web mounted upon a glass disc.

Photographic graticules with finer lines of a more robust type can now be mass-produced in a fraction of the time.

For certain purposes, metal graticules containing perforations are used. The image produced photographically on the metal surface is used either to etch the perforations away or to build up the grid by electro-plating, the latter being subsequently stripped away from the base. In this way, small copper or nickel grids of any shape can be produced. A good example is that of the electron microscope specimen grids mentioned in Chapter 9. These consist of a disc about one-eighth of an inch in diameter containing as many holes as possible—a piece of microscopic wire-gauze would be ideal but is impracticable to make. The tiny images can be made by photographing a large indian ink drawing, say two feet in diameter, at a much reduced scale, printing many of these in rows and re-printing the whole composite sheet on metal which is then treated to produce the tiny grids needed, each containing hundreds of minute holes.

The manufacture of graticules is unfortunately a technique which, though much used in wartime, is little used in peace. Had it not been for photographic methods, there would undoubtedly have been a serious bottle-neck in the supply of eye-piece graticules for gun-sights and many other types of instruments during the Second World War.

PHOTOGRAPHY AS AN INSTRUCTOR

AN APPLICATION of photography not previously described and limited to no single technique (it may, in fact, use several simultaneously) is the use of photographs and films for instructional purposes.

Visual methods of teaching have been used for many years, the chalk and blackboard being the simplest, while in museums wider application of the principle is possible. Photography, however, possesses certain features which are superior to those of any other visual method of instruction. Rare or perishable specimens can be recorded and later shown in public anywhere and at any time. Large groups of people are able to study simultaneously what might otherwise only be available to one individual at a time. It enables movement, colour and sound to be appreciated. These brief examples demonstrate how the scope of photography is extended far beyond the realm of mere illustration, enabling elusive subjects such as manual operations, social behaviour, and life in other lands to be studied in detail under class-room conditions.

The special technique of instruction required is related to its impact upon the observer, for apart from the greater ease with which visual instruction is usually grasped, it produces a more lasting impression and often a mental reaction far beyond that stimulated by other methods of instruction. This is particularly true of motion pictures and appears to depend more upon the "atmosphere" created by the film than by the interest in its subject

matter. Similar results can be observed by the intense effect of entertainment films upon cinema-goers when the latter identify themselves completely with the action and characters depicted on the screen. Films can, and do, produce such an effect on the mind of the adolescent and the more impressionable adult that control of this medium should undoubtedly be given greater attention. Certain types of entertainment film have produced undesirable effects leading to a degree of censorship, although the problem is treated mainly on a superficial basis while that of the selection and production of entertainment films containing more desirable characteristics has received little attention.

These comments should not be construed as inferring that films and other visual aids to instruction have not been extensively used. Actually they have been widely advocated for many years and are now being used to a considerable extent in schools, universities and technical colleges, though available material is still inadequate to cover fully most subjects. In some countries this position is much improved, though the relatively high cost of producing films restricts their use to subjects for which there is a fairly general demand, and in which the general principles and methods of teaching are not liable to dispute.

It is important to remember that photographic aids to teaching are not restricted to films. "Still" photographs are often quite suitable, if not better for this purpose. It may be inconvenient to circulate enlargements in a class-room or lecture-theatre, but lantern slides can be easily prepared, enabling all observers to see simultaneously. The older type of large, glass, lantern slide has in the main been replaced by the mounted cine frame, which can be used without glass, and is, in any case, much lighter,

less fragile and less bulky than its parent. Where a series of slides has to be used in the same order several times in succession it is convenient to print them on a strip of 35 mm. film. These film-strips have the advantage of being stored rolled up, thus occupying little space and being easy to transport. They may comprise a simple series of pictures or more complex assemblies of pictures, diagrams and captions. They can be used for normal teaching purposes or in conjunction with a commentary recorded on a gramophone record, the transition from one picture to the next being indicated by an audible high-pitched "peep"—or even automatically by an ultra-sonic signal which operates the projector mechanism.

The need for such visual aids was accentuated by specialized training requirements during the Second World War. Prior to 1940, the Services had made little use of visual aids, but by 1945 they were producing training films at the rate of over 300 a year, covering tactics, gunnery, target identification, equipment maintenance, hygiene, air-raid precautions and many other subjects. Hundreds of film-strips were also made for use where they were better adapted to the type of instruction required.

Many specialized forms of training were developed round this form of instruction. Aircraft gunnery and navigation were taught by "synthetic" trainers in which the trainee saw a moving panorama provided by films and slides. Since the war, this system has been applied to a method of training car drivers and to a testing equipment designed to indicate a driver's speed of reaction when confronted by sudden road emergencies. A dummy car, with a full set of controls, is positioned before a screen on which is projected a film of a street, simulating movement as though the dummy car were being driven along its length and in which possible causes of numerous accidents

occur. The reactions of the driver, indicated by instruments attached to his controls, are recorded and used for corrective instruction.

The value of "visual aids" in the Services led to greatly renewed interest in their use in schools after the war. The problem is, however, not so simple when adapted to these bodies, for the subjects taught are more diverse and the methods used depend far more upon individual teachers. The personality of the teacher and subsequent effect on the pupils is of prime importance and "synthetic" methods super-imposed from outside the class are less likely to be effective than they were under Service conditions. There can, however, be no excuse for ignoring the exceptional value of this method of illustration, and teachers will no doubt adapt themselves to use films, film-strips and slides in conjunction with other methods of instruction. Projectors are available at a large number of schools and more are constantly being provided. Films and "still" pictures covering most subjects at present taught are gradually being made available.

Children can thus be taught geography, history, science and even languages, in a way which increases the interest value of the subject and enables them to retain the main facts. The teaching of skilled crafts can be assisted by films of experts at work, and art lessons improved by colour illustrations of works of art, or of painters, sculptors and designers at work. At university level, medical students can be shown surgical operations, including those only rarely performed and in detail far surpassing that seen by personal observation in the operating theatre. Biology students can be shown records of animals in native surroundings, and geologists specimens of rock formations found in remote parts of the world.

Possibly the most fruitful, and yet little used, application of such aids to instruction is in the training of industrial workers. This applies to all levels, from apprentices to management. Apprentices were at one time taught solely by assisting an experienced operative. This was often a slow process and one in which much depended upon the characters of the two people concerned. Since then instruction has been re-organized, part being given at classes dealing with the theory of the subject and part (often a major part) by demonstrations arranged in the workshop or in special training shops. However, lack of co-ordination between the theory and practice, and lack of suitable training equipment often confuses apprentices. Visual aids enable these defects to be minimized and provide a far wider horizon for the apprentice. Close-up views, explanatory diagrams, slow-motion films, examples of expensive or rare plant or equipment, motion-study methods all assist. Moreover, the film can teach mental attitudes as well as mere manual techniques. Hence it provides an ideal method of assisting the training of supervisory staff and management in such matters as introducing new workers, joint consultation, discipline, safety, time and motion study and other vital factors of their work which, in the past, have all too often been acquired in haphazard fashion from older men or sometimes ignored altogether. Unfortunately, the number of films and "still" pictures available is limited, as industrial training methods of any type are still in their infancy. The vast majority of firms, in Britain at any rate, still pursue rudimentary systems or even ignore the need for organized training.

In technical education, which is closely allied to industrial training, photographic visual aids are used very infrequently. To take a typical example, there are

practically no films dealing with photography—a subject which lends itself to treatment by means of visual aids, and the few lantern slides available are restricted to certain aspects of the subject. The contents of this book could well have been made more easily assimilable and comprehensive—or even replaced—by a series of films and film-strips, so designed as to link together and cover the entire field of photography. There is ample material available for this purpose if it could be collected. The chapters on recording, infra-red, ultra-violet, radiography and atomic physics would gain enormously by film illustrations of the techniques in use, while the contents of Chapter 10, “Recording and Analysis of Motion,” would be greatly enhanced by actual examples of slow-motion, ultra-high-speed and time-lapse films. Similarly, the uses of photography in production processes would gain enormously by the addition of film illustrations.

Beyond this, however, the fundamental principles governing the applications of photography could be explained simply and clearly by the use of moving diagrams and cartoons. Some experiments in book illustration have been made in this direction but there are still many problems to overcome before this application of photography is put to general use.

BIBLIOGRAPHY

There are relatively few books covering the various branches of applied photography, though many technical books make mention of certain limited aspects in this field. Several thousands of articles exist, most of a highly specialized nature. This list is therefore intended as a general introduction to the literature, and includes books and articles which the author has found to be of particular value to readers requiring guidance when making their first acquaintance with the subject. Most items listed below demand no detailed knowledge of the technique of photography.

I. General

Photography as a Scientific Implement (a collective work).

Blackie, 1924. Although now quite out of date, this book is still of some interest, as the fundamental principles it covers remain unchanged.

Kodak Data Book of Applied Photography (4 volumes), 2nd Edn. Kodak Ltd., 1951.

Handbook of Photography. K. Henney and B. Dudley; McGraw Hill, 1939. Concerned more with photographic technique than applications.

Photography in Engineering. C. H. S. Tupholme; Faber and Faber, 1945.

Modern Applications of Photography. D. A. Spencer; Science News 7 (Penguin Books), 1948, pages 74-111.

Applied Photography. G. A. Jones; *Discovery*, Vol. 5, 1947, pages 184-88.

Scientific Photography. G. I. P. Levenson; Photography Year Book, Press Centre Ltd., 1951, pages 90-101.

Photographic Abstracts. Published quarterly by the Scientific and Technical Group of the Royal Photographic Society, London.

II. Specialized

- Document Photography*, 3rd Edn. H. W. Greenwood; Focal Press, 1947.
- Copying Technique*. F. R. Fraprie and R. H. Morris; American Photographic Publishing Co., 1946.
- Microfilming*. R. de Sola; Essential Books, 1944.
- The Photographic Recording of Cathode Ray Tube Traces*. R. J. Hercock; Ilford Ltd., 1947.
- Spectroscopy in Science and Industry*. S. J. Lewis; Blackie, 1933.
- Photography in Astronomy*. E. W. H. Selwyn; Eastman Kodak Co., 1950.
- Science for the Prosecution*. J. Grant; Chapman and Hall, 1941.
- Photography by Infra-red*, 2nd Edn. W. Clark; Chapman and Hall, 1946.
- Infra-red Photography*, 2nd Edn. S. O. Rawling; Blackie, 1935.
- An Introduction to Medical Photography*. J. Hunt; Staples Press, 1950.
- Photographic Aids to Clinical and Dental Practice*. J. M. Dyce; Staples Press, 1948.
- Medical Photography—Radiographic and Clinical*, 4th Edn. T. A. Longmore; Focal Press, 1949.
- Handbook of Industrial Radiology*. J. A. Crowther; Arnold, 1944.
- Photographic Emulsion Technique*. J. Rotblat—Chapter 3 of *Progress in Nuclear Physics*, I, edited by O. R. Frisch; Butterworth-Springer, 1950.
- The Photographic Study of Rapid Events*. W. D. Chesterman; Clarendon Press, 1951.
- High Speed Photography*. G. A. Jones; Chapman and Hall, 1952.
- Flash!* H. E. Edgerton and J. Killian; Hale, Cushman and Flint, Boston, Mass., 1939.
- Photographic Surveying*. B. B. Talley and P. H. Robbins; Pitman, 1945.

BIBLIOGRAPHY

- Aerial Photographs*. A. J. Eardley; Harper, 1941.
- Photo-micrography*. R. M. Allen; Chapman and Hall, 1943.
- Metallography*, 6th Edn. C. H. Desch; Longmans, 1944.
- Practical Electron Microscopy*. V. E. Coslett; Butterworth, 1951.
- Beyond the Microscope*. K. M. Smith; Pelican, 1943.
- Photographs and the Printer*. F. H. Smith; Focal Press, 1948.
- Modern Illustration Processes*, 3rd Edn. C. W. Gamble; Pitman, 1950.
- Science in Films*. Edited by B. Lloyd; Sampson, Low, Marston & Co., 1948.
- Preparation and Use of Visual Aids*. K. B. Haas and H. Q. Packer; Prentice Hall Inc., 1946.

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